New Materials and Methods for

WATER RESOURCE MANAGEMENT

A Report to the Committee on Public Works, United States Senate

May 1962

Jones
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Agricultural Research Service

UNITED STATES DEPARTMENT OF AGRICULTURE

The mention of patented materials or equipment in this report does not imply approval of the product to the exclusion of others that may also be suitable.

Acknowledgment is made of the assistance of staff members of the two Divisions who assisted in compiling and summarizing the data. Special acknowledgment is given to Dean C. Muckel, agricultural engineer, who coordinated the report.

NEW MATERIALS AND METHODS

For

WATER RESOURCE MANAGEMENT

A Report to the Committee on Public Works, United States Senate, May 1962

Prepared by

Soil and Water Conservation Research Division

and

Crops Research Division

Agricultural Research Service

U.S. DEPARTMENT OF AGRICULTURE

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INTRODUCTION

This report was prepared as a result of Committee Resolution of the Committee on Public Works, U. S. Senate. By unanimous vote, it was resolved that the Committee shall institute a study and investigation of new materials, use of new materials and new designs, and methods that may be adapted in flood control and rivers and harbors, roads and highways, public buildings, water pollution control, water power and other development, utilization, preservation and protection projects, and that a committee report shall be prepared thereon and submitted to the Senate. The report herein describes the research being carried on throughout the United States by the Soil and Water Conservation Research Division, Agricultural Research Service, on new materials, equipment, and methods for soil and water conservation. Those parts of the report dealing with the use of chemicals in the control and management of aquatic weeds, brush, and phreatophytes were prepared by the Crops Protection Branch of the Crops Research Division.

Throughout the report it will be noted the terms "uneconomical," "unsatisfactory," "needs further study," etc., are used. These are not to be construed as being final or that the materials discussed are to be no longer considered in water conservation. Sufficient results have been developed through research to show that the potential of these materials is enormous and that in many cases only slight improvement or alterations of the materials stand in the way of widespread use. Procedures and methods of using new materials in the field also will require further study to assure that their widespread use will be economical. After careful analyses of present evidence it must be concluded that we are on the threshold of a widespread use of new materials in water conservation and that many practices long considered standard will be altered substantially.

A very large part of the research on use of new materials in water conservation has been made possible by the cooperation of numerous industrial and commercial enterprises. Many new materials and equipment tested have been donated to various research locations. Without this cooperation the advancement now existent could not have been attained.

The Nation's Water Problem

At the National Water Research Symposium held March 28-30, 1961, Washington, D. C., the Hon. Orville L. Freeman, Secretary of Agriculture, stated in specific terms the overall water problem of the Nation, when he said: "We are a fast-growing nation. Our national population is rising at the rate of 340 persons per hour, 8,000 per day, 3 million per year. This is a faster rate than that of any major industrial nation and

faster than many underdeveloped countries. --- If the present trends continue, just 39 years from now we will have to provide for twice as many people as we now do.

"But the demand for water is growing even faster than population. Now in 1961 we use about 300 billion gallons of water per day. In 1980—only 19 years hence—we will require 600 billion gallons of usable water per day.

"That's the size of the problem."

Agriculture, being the greatest user of water, is directly concerned with the increasing demand for water. Irrigation now uses about 46 percent of all the water used in the United States (fig. 1).1/

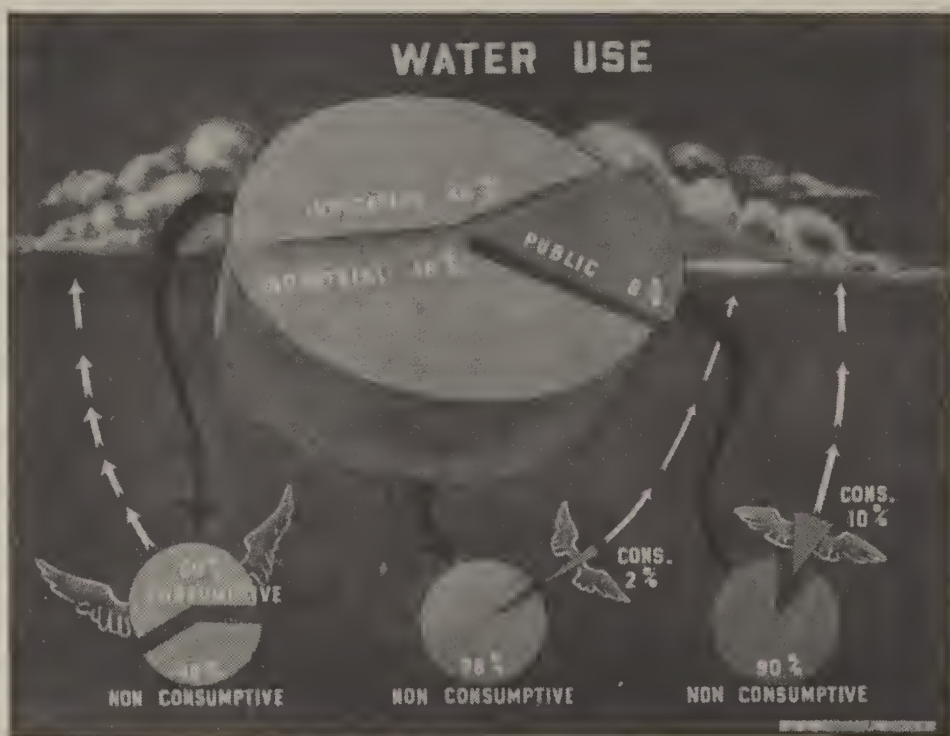

FIGURE 1.–The amount of water consumed is one of the most important problems of water use. Water that is evaporated or is incorporated in a product is consumed. Irrigation accounts for 80 to 90 percent of all water consumed. (Courtesy of U.S. Geological Survey.)

Estimates by the U. S. Geological Survey2/ indicate a total withdrawal of water in the United States of about 1,740,000 million gallons per day during 1955. Of this amount

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1/ Committee Print No. 1, "Water Resources Activities in the United States," prepared by the U.S. Geological Survey, for the Select Committee on National Water Resources pursuant to S. Res. 48, 86th Cong., 1st Sess. Further references to materials issued by the Select Committee will be identified simply as "committee print" followed by the appropriate number.

2/ MacKichan, K. A. Estimated use of water in the United States, 1955. U.S. Geol. Survey Cir. 398.

about 1,500,000 million gallons was withdrawn for production of water power. The 240,000 million gallons remaining was withdrawn for public supplies, rural use, self-supported industrial use, and irrigation. Only about a fourth of all water withdrawn is consumed. Most of the water consumed is used for irrigation; a fact of added importance when it is considered that irrigation is practiced at times and places where the water supply is likely to be inadequate. This report deals with use of water for agricultural purposes and the potential conservation practices that will lead to a more efficient use and reduction of water loss.

About 123 million acre-feet of water was used in 1955 to irrigate 34 million acres (1,000 acre-feet per year equals 0.89 million gallon per day). Of this amount 91 million acre-feet was delivered to farms and 32 million acre-feet was lost in conveyance. Generally, not more than 60 percent of the water delivered at the farm headgate is consumed by crops.[3/] Therefore, of the total amount of water use charged to irrigation only about 45 percent goes into crop production. Almost 90 percent of the water withdrawn for irrigation in the United States is used for irrigation in the 17 Western States where rainfall is inadequate for profitable crop production and evaporation losses, evapotranspiration rates of nonbeneficial plants, and seepage losses are high. However, irrigation is increasing in the Eastern States (table 1).

TABLE 1.—Total irrigation water requirements for Eastern and for Western United States for 1954, and that estimated for 1980 and 2000[1/]

Area and water use	1954	1980	2000
Eastern United States:			
Irrigation acreage------------ thousand acres---	2,002	3,707	15,068
Storage and diversion--------- thousand acre-feet	5,388	8,337	29,178
Irrigation water requirement -- thousand acre-feet	4,736	7,429	26,589
Western United States:			
Irrigation acreage------------ thousand acres---	27,550	32,993	40,445
Storage and diversion--------- thousand acre-feet	189,176	172,180	169,428
Irrigation water requirement -- thousand acre-feet	109,961	106,224	110,652

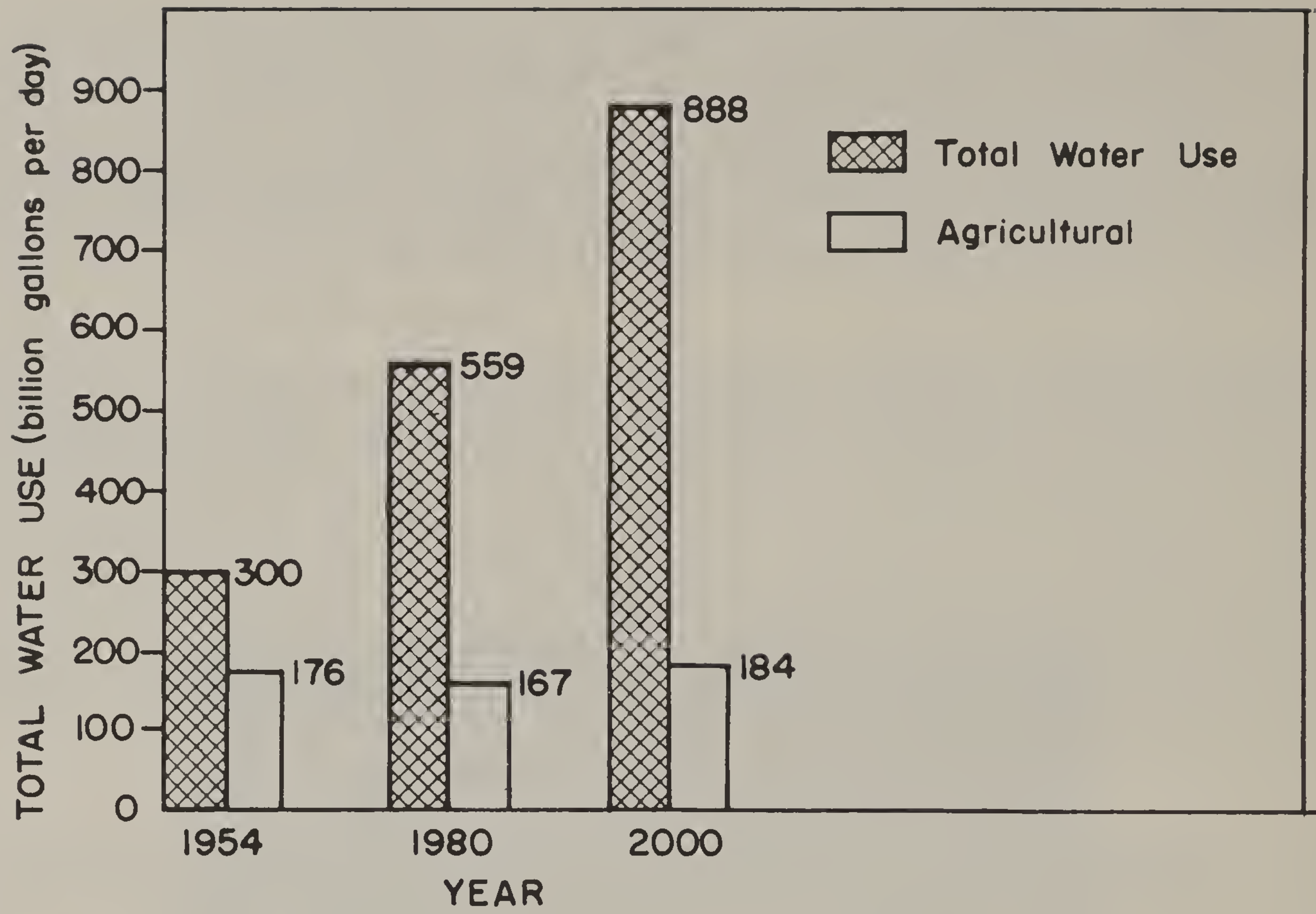
1/ From Committee Print No. 12 (p. 19). Based on medium population level projections.

Nathaniel Wollman reported agriculture will require an average daily withdrawal of 184,000 million gallons of water per day in the year 2000 (fig. 2).

Water Losses

The opportunities to improve and conserve irrigation water supplies are many. These can best be evaluated by consideration of the various losses now occurring.

3/ Blaney, H. F. Climate as an index of irrigation needs. In Water, U. S. Dept. Agr. Yearbook 1955, pp. 341-355.



Based on Projections by Nathaniel Wollman in Committee Print No. 32, pp. 39, 40, 41 (Medium population-level projection).

FIGURE 2.–Total demand for water and proportion required for agricultural use for 1954, 1980, and 2000.

Evaporation

Evaporation occurs from free water surfaces of water held in storage reservoirs, natural streams, and conveyance canals and from the soil surface. Studies of evaporation 4/ from storage reservoirs indicate that for long periods of deficient streamflow some reservoirs may yield, for useful purposes, as little as 50 percent of the total supply, the balance being lost by evaporation through years of carryover storage. It is estimated that annual losses exceeding 6 million acre-feet occur from man-made reservoirs in the 17 Western States. 5/ Most estimates of evaporation from storage reservoirs are based on reservoirs ranging in size from 500 to 50,000 acres surface areas. 6/ How-

4/ Blaney, H. F. Evaporation from water surfaces in mountain areas of Western United States. Assoc. of Internatl. D'Hydrol. March 1960.

5/ Myers, L. E., Jr. Conservation of irrigation water supplies in arid climates. Wyo. Agr. Expt. Sta. Bul. 367. 1960.

6/ Committee Print No. 23.

ever, there are only 1,250 really big reservoirs in the United States, whereas there are millions of farm ponds. Most of these ponds have water surfaces of about 1/4 acre to 2 acres and maximum depths that range from 8 to 15 feet. The storage efficiency of these ponds must vary widely; in some cases evaporation and surface losses may far exceed the yield of usable water.

The range of evaporation from a canal is considered to be a small part of the water carried and rarely exceeds 2 percent of the water diverted and more often is less than 1 percent. 6/

Evaporation of water from the soil surface is one of the main ways water is lost in any agricultural area. 7/ It is estimated that of the amount of water that reaches the root zone under irrigated conditions, up to 50 percent is lost by evaporation from the soil surface. The problem is of equal or more importance on nonirrigated areas. In the summer-fallow area of the Great Plains, it is estimated that at least two-thirds of the rainfall is lost by evaporation. Studies have shown that if evaporation could be reduced by the equivalent of 3 inches of precipitation the 10 Great Plains States alone would have an additional 300 million acre-feet of water—enough to fill Lake Mead.

Seepage

Seepage occurs from natural stream channels, canals, and reservoirs. The actual water loss as a resource is difficult to assess, because a part seeps into the ground and can be recovered through wells. In some areas the water may not only be lost but creates a further loss by damaging lower lying lands through development of salt-affected soils and swamp areas that are unfit for agriculture.

Of the 123 million acre-feet of water used in 1955 to irrigate 34 million acres, 32 million acre-feet was lost in conveyance. 8/

This conveyance loss includes seepage—some of which is recovered—evaporation, and evapotranspiration by phreatophytes (deep-rooted nonbeneficial plants) that cannot be recovered. As with estimates of evaporation from reservoirs, only the larger structures are included. To the farmer the seepage losses occurring on his farm laterals and ditches may mean just as much or more to him as the losses on the larger canals and channels that bring water to his land.

Unlined ditches in the more porous soils may lose more than 10 percent of the irrigation water per mile. 9/ Seepage losses of 4.8 cubic feet per second per square foot every 34 hours have been measured in Utah. 10/ Seepage losses from farm ponds may be considerable when the reservoirs are first constructed, but tend to decrease as silts and sediments accumulate in the pond.

7/ Kelley, O. J. Role of research in present and future efficient use of water in irrigated agriculture. In Natl. Water Res. Symposium, March 28-30, 1961. Sen. Doc. 35, 87th Cong., 1st Sess.

8/ MacKichan, K. A. Estimated use of water in the United States. U. S. Geol. Survey Cir. 398.

9/ Criddle, W. D. Reducing water losses from storage and conveyance. In Natl. Water Res. Symposium, March 28-30, 1961. Sen. Doc. 35, 87th Cong., 1st Sess.

10/ Lauritzen, C. W., and others. Lining canals and reservoirs to reduce conveyance losses. Utah Agr. Expt. Sta. Cir. 129. 1952.

On some arid Southwest areas only 5 percent of the water falling on the watershed as precipitation gets into the stream channels. The remaining 95 percent evaporates from the soil or is lost by evapotranspiration.

Losses From Phreatophytes and Aquatic Weeds

The loss of water by phreatophytes is of growing concern in the semiarid West. Phreatophytes grow in all 17 Western States. It is estimated that there are now 16 million acres of phreatophytes of low beneficial use in these states. There are about 75 species of plants in the western United States that have been identified as phreatophytes.[11] They have only one common characteristic—their dependence on ground water when growing under natural conditions. Saltcedar is one of the largest water wasters. It is an aggressive, naturalizing, and rapidly spreading plant. Table 2 shows the rapidity of its growth in two areas of the Southwest.

TABLE 2.—Growth of saltcedar infestation in New Mexico[1]

Area and date	Growth of infestation
Pecos River basin, between Santa Rosa, N. Mex., and the Texas State line:	
Prior to 1912	None
1912	Few seedlings
1915	600 acres
1925	12,300 acres
1939	15,200 acres
1946	26,200 acres
1953	36,800 acres
1955	41,000 acres
1960	50,000 acres
Rio Grande basin in New Mexico from Bernardo to San Marcial:	
1914	1,200 acres
1935	3,500 acres
1955	52,000 acres

1/ From Committee Print No. 21.

Not only has the general area of saltcedar infestation been increasing but also the area of dense growth has increased. As an example, in the Pecos River Basin there were only 500 acres of dense growth of saltcedar in 1939, but by 1950 this had increased to 7,700 acres. In the same period the area of medium-dense growth had increased from 3,500 acres to 10,000 acres.

Studies by the United States Department of Agriculture of evapotranspiration indicate that saltcedar and cottonwoods use from 50 to 100 percent more water than most

11/ Robinson, T. W. Phreatophytes. U. S. Geol. Survey Water Supply Paper 1423, 84 pp. 1955.

agricultural crops.12/ Annual consumptive use of water by phreatophytes, estimated to cover 15 million acres of bottomlands in the 17 Western States, is estimated to be more than 25 million acre-feet.13/ 14/

Brush species of the chaparral type and weeds on watersheds and adjoining grasslands reduce water yields from springs and streamflow.15/ Conversion of brushland and weed-infested lands to grass can increase the availability of water for livestock, irrigation, and the amount of water stored in the soil.

Aquatic weeds reduce markedly the velocity of flow of water in irrigation and drainage canals. The reduced velocity causes high water levels in canals and streams that result in (1) flooding, (2) seepage into adjoining areas or poor drainage, (3) breaks in canal banks, and (4) inadequate delivery of irrigation water to farms located at a distance from the water source. In addition, reduced velocity of flow causes increased siltation, reduced carrying capacity of waterway, and necessitates more frequent dredging. Aquatic weeds that break loose and weeds of the floating type obstruct weirs, gates, and other structures. Also, algae and fragments of plant material clog sprinkler irrigation systems. Weeds on watershed areas utilize appreciable amounts of water and thereby deny its use for the production of food, feed, and fiber.

Aquatic weeds reduce recreational values by interfering with fishing, swimming, boating, hunting, and navigation of otherwise navigable streams. The decaying organic matter produced by aquatic weeds causes off flavors in potable waters.

Losses from weeds in western irrigation systems in 1957 are shown in table 3.16/ The total estimated water loss of 1,966,068 acre-feet in the 17 Western States would have been enough to irrigate 330,000 to 780,000 acres of cropland, depending on the length of the growing season, evaporation losses, and other factors.

The cost of water lost to transpiration by the weeds is the actual cost of the water to the water users. The costs among the 47 reporting districts ranged from $0.40 to $10 per acre-foot. With these rates per acre-foot, the total cost of water lost in the 47 reporting districts was $678,966, and the total estimated cost in the 17 Western States was $3,626,742.

Other costs that are caused by weeds, such as damage to canals, structures, crops, and farmland, brought the total cost of weeds for the reporting projects to $993,216, and for all irrigation systems in the 17 Western States to $5,739,164 (table 3).

The data on acreages of weeds in flood plains and reservoirs and losses from weeds in these situations are incomplete. Therefore, these data are not extrapolated into the estimates given in table 3.

12/ Blaney, H. F. Consumptive use and water waste by phreatophytes. Amer. Soc. Civil Engin. Proc. 87(IR-3). 1961.

13/ Robinson, T. W. Phreatophytes and their relation to water in Western United States. Amer. Geophys. Union Trans. 33: 57-61.

14/ Committee Print No. 21.

15/ Biswell, H. H., and Schultz, A. M. Spring flow affected by brush. Calif. Agr. 11(10): 3-4, 10. 1957.

16/ Timmons, F. L. Weed control in western irrigation and drainage systems. U. S. Dept. Agr. ARS-34-14, 21 pp. 1960.

TABLE 3.—Losses from weeds in western irrigation systems, 1957

Item	Reported by 7 regions (47 districts)	Extrapolated totals in 17 Western States
Water lost:		
Aquatic weeds---------- acre-feet ----	252,861	1,375,746
Ditchbank weeds-------- acre-feet ----	76,082	590,322
Total------------- acre-feet ----	328,943	1,966,068
Cost of water lost:		
Aquatic weeds----------- dollars -----	547,169	2,667,502
Ditchbank weeds--------- dollars -----	131,797	959,240
Total--------------- dollars -----	678,966	3,626,742
Cost of other damage:		
Aquatic weeds----------- dollars -----	178,250	1,304,488
Ditchbank weeds--------- dollars -----	136,000	807,934
Total--------------- dollars -----	314,250	2,112,422
Total losses:		
Aquatic weeds----------- dollars -----	725,419	3,971,990
Ditchbank weeds--------- dollars -----	267,797	1,767,174
Total--------------- dollars -----	993,216	5,739,164

Effect of Water Loss Reduction

If the various water losses pertinent to the use of water for agriculture are combined, it is apparent from the preceding discussion that substantial savings can result from conservation practices and increased water-use efficiency.

A conservative estimate of net losses[17/] that can be reduced would appear to be about 50 million acre-feet annually. A 20-percent reduction of these losses would increase usable agricultural water supplies by 10 million acre-feet, nearly equal to the average annual flow of the Colorado River. Substantial increases can also be realized by other means, such as increasing runoff from watersheds and reducing evaporation from irrigated fields and from dryland farmed areas after rains.

Increases of water supplies for agricultural purposes can come about by reduction of evaporation from water and soil surfaces, reduction of conveyance losses, reduction of evapotranspiration by reducing growth of nonbeneficial plants, particularly phreatophytes. Further increases can be obtained by more efficient use of water on farmlands.

17/ Myers, L. E., Jr. Conservation of irrigation water supplies in arid climates. Wyo. Agr. Expt. Sta. Bul. 367. 1960.

Estimates by the U.S. Geological Survey[18/] indicate that by 1980 the following annual savings of water could be made in the United States:

- 2 million acre-feet in reservoirs if treated with monolayers.

- 1.5 million acre-feet from seepage if canals are lined and subgrade-treated and if closed conduits are used.

- 1 million acre-feet if nonbeneficial plants are eradicated.

In addition to the above estimates, if water application efficiency were increased by 10 percent, it would provide an annual saving of 6 million acre-feet.

Although it is known much water is evaporated from soil surfaces after irrigation and after rains, reliable estimates cannot be made as to the extent of reduction possible. Research has indicated this evaporation can be reduced by various means, but it is not yet economically feasible, and no attempt is made here to evaluate it.

In many areas of the West irrigation supplies are largely obtained from ground water: notably, the High Plains of Texas, San Joaquin Valley of California, and large areas in Arizona and New Mexico. Although the ground water supplies may amount to extremely large quantities, they are not unlimited as evidenced by falling water tables. Replenishment of the ground water supplies by artificial means (water spreading, recharge wells, replenishment irrigation, etc.) is a growing practice. Conservation of flood runoff and off-season stream flows for storage underground serves to increase the water supplies for agricultural purposes.

In areas of very limited water supply development of small quantities of water is extremely important. For example, many semiarid areas receive sufficient precipitation to produce considerable forage. The problem is to provide drinking water so livestock can utilize this forage. This problem is partially met by manmade reservoirs. But percolation, seepage, and evaporation make them highly inefficient. Most of the precipitation that falls, particularly in low-rainfall areas, enters the soil and never produces any appreciable runoff. A new development indicates a partial solution to this problem: Covering a land area with nonabsorbent, watertight material can save essentially all precipitation. Materials that might be used for ground covers to increase runoff include asphalt, plastic, and butyl rubber. Chemical sealants also have possibilities. This procedure is appropriately named "water harvest." From the water harvest area the water is directed to a large collapsible bag in which all the water collected can be held indefinitely without loss.

The idea of water harvest areas is also being studied in dryland farm areas to collect and use the precipitation more efficiently. In semiarid areas of the Great Plains, for example, considerable runoff frequently occurs during heavy summer storms. Research has shown it is possible to save much of this water by leveling a part of the land so that it will catch and hold runoff from other areas until it percolates into the soil. In other words, harvest the water from one part of land for use in another part.

Salt water conversion and weather modification are intriguing possibilities of increasing water supplies. They are, however, presently beyond the economical reach of agriculture.

18/ Committee Print No. 23.

Water problems and corrective measures are many sided and far reaching. No single phase of the problem, no single corrective measure stands out above the other, or stands in the shadow of another. Most water supply problems are local problems. They can be solved by one or more methods that might not be suitable solutions for other localities. Hence, the need for many approaches. If we could increase the total available supply of water we would not solve all the local water supply problems. 19/

REVIEW OF NEW MATERIALS AND METHODS TO CONSERVE WATER RESOURCES

Increase of Runoff From Watersheds

In certain areas of the West, where a major portion of the precipitation may be lost by evaporation from soil or used by noneconomic vegetation, practices to increase runoff from such watersheds are being studied. These practices include (1) use of chemicals to kill brush and trees; (2) materials to stabilize and waterproof soil surfaces; and (3) ground covers to aid in collecting water.

Vegetation Management

Various measures of eliminating brush from watersheds to increase and conserve water have been studied. At present, many species cannot be controlled economically with chemicals and equipment now available and present knowledge.

Mechanical control measures include destruction of tops, root plowing, and chaining. These methods are expensive and fail to give satisfactory control, particularly of root-sprouting species and where mixed types and sizes of brush occur.

In limited areas, top growth is killed by burning, but fires frequently get out of control and devastate large areas of valuable timberlands.

Herbicides such as 2, 4, 5-trichlorophenoxyacetic acid (2,4,5-T), 2-(2, 4, 5-trichlorophenoxy)-propionic acid (silvex), 2, 4-dichlorophenoxyacetic acid (2, 4-D), and 3-phenyl-1, 1-dimethylurea (fenuron) are erratically successful in killing chaparral, juniper, and other brush species.

The use of biological agents for brush control has received scanty attention. Conflicts in interest concerning certain species that are weeds in one location but desirable plants in another tend to limit the use of biological control agents for the control of woody plants.

19/ Williams, D. A. Water supply. In Natl. Water Res. Symposium, March 28-30, 1961. Sen. Doc. 35, 87th Cong., 1st Sess.

Soil Treatment

Experiments at Logan, Utah, demonstrated that runoff could be increased by spraying with asphalt cutbacks, emulsions, and other asphalt products—including oils. The hot-mix design for the asphaltic concrete correspond to that used for roads, i.e., sand and gravel aggregate (3/4-in. max.) stabilized with about 8 percent of paving grade asphalt. Membranes constructed of blown asphaltic cements, including the catalytically blown asphaltic cement, are used extensively by the U.S. Bureau of Reclamation as buried canal linings.

The asphaltic concrete was costly and, although partially effective over a long period, tended to break up and lose its effectiveness; the exposed membrane, although initially very effective, soon went to pieces.

Asphalt emulsions compounded with cationic emulsifiers are more resistant to weathering and more tightly bonded to soil than the materials listed above. Many soils are anionic and tend to repel the previously used anionic asphalt emulsions. Cationic asphalt emulsions bond tightly to these soils. Use of cationic emulsifiers also increases resistance to weathering, although the exact mechanism responsible for this improved weathering is not known at the present time.

Small soil trays treated with cationic asphalt emulsion at the rate of 0.1 lb. actual asphalt per square foot have been exposed to outdoor weathering conditions for 2 years at the U.S. Water Conservation Laboratory, Tempe, Ariz., and the soils are still protected against erosion in these trays. Field plots treated with these emulsions are still protected against erosion after 1 year of exposure. These test plots are on a slope of about 5 percent and have been subjected to rainfall and wind. The low rates of asphalt application would not protect the soil against erosion by flowing water in a conveyance channel.

Toxicity is not expected to be a problem in the use of cationic asphalt emulsions, since nontoxic emulsifiers can be utilized. Oxidation products of asphalt are not believed to be toxic but should be investigated. The durability of the material will depend upon the quantity applied. Additional work on this question is needed and in progress.

The cost of cationic asphalt emulsions containing 5.5 pounds of asphalt per gallon should be about 25 cents per gallon, including the manufacturer's reasonable profit. Asphalt is readily available.

Other chemicals screened to act as binders and sealants of soil surfaces were sodium silicate, resins, silicons, calcium, acrylate, acrylamides, polyacrylamide, and others that were primarily water repellants and had little stabilizing effect.

Ground Covers

Ground covers—plastics, butyl, metal, asphalt planking—to increase runoff are being investigated at several locations. Most covers are used in "water harvest" areas where the precipitation is collected at one point for use at another. The ground covers also protect newly shaped and seeded areas from erosion.

In certain arid regions, lack of water for livestock limits the pasturing of forage. Precipitation in these areas usually occurs in small amounts and at infrequent intervals.

Normally the ground is dry and the water absorbed as it falls. Only in the event of large storms is there sufficient water to cause runoff. A few stock ponds have been developed to collect water during these periods of runoff, but generally the ponds receive little runoff and seepage losses are high.

In western Box Elder County, Utah, precipitation occurred only 34 days in 1954. Precipitation from these storms totaled 8.08 inches, and yet no runoff occurred during this period. But the amount of water falling on an acre was 217,800 gallons. If this water could be collected by a ground cover and stored it would be sufficient to water 100 head of cattle 217 days.

Early work with ground covers consisted primarily of performance testing on a small scale. The materials included asphalt mixes, such as are used on roads, and asphalt membranes of the type used for canal lining. Later, plastic films—polyethylene, vinyl, and mylar—were included.

The good weathering properties and low cost of black polyethylene film led us to a rather large-scale installation of polyethylene film as a ground cover in 1955. At this time a 1-acre area in western Box Elder County, Utah, was covered with an 8-mil black polyethylene. The film was delivered in lengths 190 feet long and 14 feet wide. Each length was provided with a one-foot tail along the center line for anchoring. Anchoring was accomplished by burying the tail in a trench and the individual lengths were bonded together with a band sealer. The test proved a failure because of poor field seams, which loosened under the high winds to which this area is subject and because of bird damage. In 1956 a part of the polyethylene was replaced with an 8-mil olive-green vinyl film to which a partial topping of gravel was added. The better seams and gravel solved the wind problem and greatly reduced bird damage. After 2 years, however, serious degradation in the form of hardening accompanied by numerous breaks developed due to migration of the plasticizer in the vinyl film.

At about the same time, a small piece of butyl sheeting was exposed adjacent to the ground cover installation in western Box Elder. The butyl has not shown any signs of degradation through weathering, nor has it been subject to bird damage. The small scale of the installation, however, does not warrant a comparison as to its susceptibility to bird damage.

A test area in the vicinity of Logan, Utah, was established in 1958. The ground covers in this test area are approximately 40 by 40 feet. An 8-mil vinyl ground cover was installed in 1958, and a 30-mil butyl and an asphalt-coated burlap ground cover installed in 1959. For the first 2 years these ground covers were equally efficient, collecting almost 100 percent of the precipitation. In the third year a hard storm knocked holes in the vinyl, and as a result the efficiency of this cover decreased; after 4 years the vinyl film is showing considerable degradation in the form of new breaks and some stiffening in localized areas owing to migration of the plasticizer. The butyl and asphalt-coated jute ground covers are still collecting 100 percent of the precipitation.

A necessary part of any ground cover installation is a storage structure. Any conventional structure can be used so long as it is watertight. Since the evaporation is 10 to 12 times the precipitation in many of the areas where ground covers will have their greatest application, stored water should be protected from evaporation. One way to do this is with bags constructed of plastic and rubber. In the smaller size this can be self-supporting (fig. 3). This type can be used on top of the ground. Where larger storage structures are desired, the bag should be placed in an excavation, so that when it is

filled with water, the hydrostatic pressure developed will be taken by the bottom and sides of the excavation and not stress the bag (fig. 4).

FIGURE 3.—Butyl-covered nylon bag assembly, with ground cover in background. Bag has a capacity of 1,600 gallons, which can be filled with approximately 1 inch of rain on the ground cover.

Cost would appear to be about the only limiting factor involved in developing water by this means, when we consider that two-thirds of all the precipitation is lost through evaporation and transpiration without producing any economic gain. [20] The cost of developing water with ground covers depends on two things—cost of the ground cover, including installation and replacement, and the precipitation in the area. Based on the assumption that a ground cover in place will cost $1.00 per square yard and precipitation is from 8 to 18 inches, the cost per 1,000 gallons will vary from $0.86 to $3.10 per 1,000 gallons (table 4).

Not only do ground covers offer an opportunity to develop water for livestock but culinary water as well. Culinary water developed by this method will be essentially free of salts and organic materials frequently found in water from other sources. Except for cost, it even offers a potential source for irrigation: if the precipitation falling on a section of land were collected and stored it would be sufficient to irrigate 213 acres, allowing 4 acre-feet per acre.

20/ Hendricks, E. L. Hydrology. Science 135(3505): 699-705. 1962.

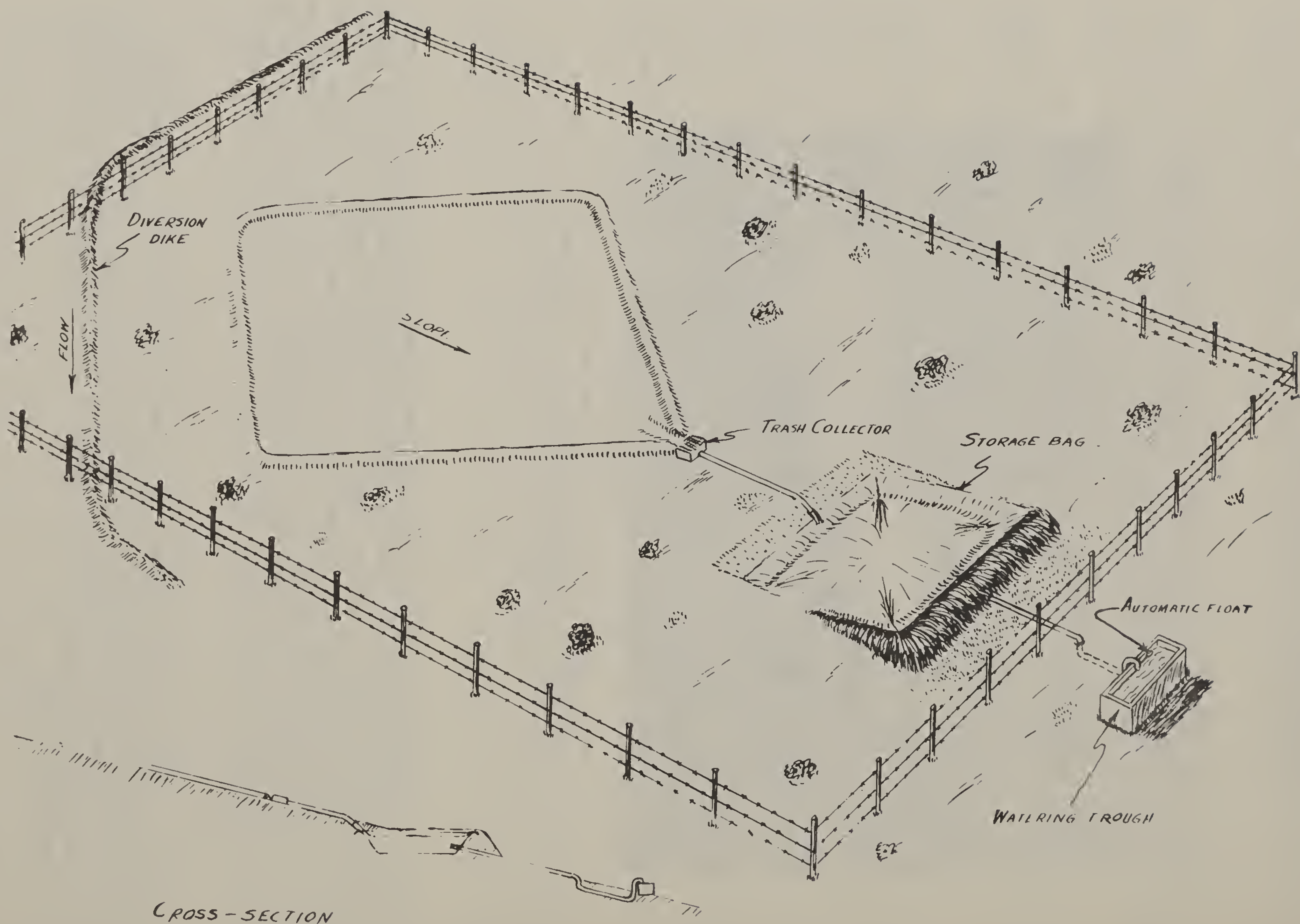


FIGURE 4.–Layout for collection of water from a ground cover installation. The bag has not been filled.

TABLE 4.—Cost of developing water by means of ground covers[1]

Annual precipitation (inches)	Life of cover	Cost per 1,000 gallons
	Years	
8	10	$3.10
12	10	2.08
18	10	1.37
8	15	2.32
12	15	1.54
18	15	1.03
8	20	1.93
12	20	1.29
18	20	.86

1/ Assuming ground cover in place cost $1.00 per square yard.

At two locations (North Dakota and Texas) ground covers are being tested for use on contributing areas; in other words, the covers concentrate the runoff on cropped benches. At the Mandan Field Station (N. Dak.) black ployethylene plastic sheeting (0.006-inch thickness) is being used to cover an area that will contribute runoff which will collect in a conservation bench terrace below. The contributing area and the bench are each 30 feet wide.

The average (1959 through 1961) soil moisture storage and yields of continuous wheat on the bench with a plastic-covered contributing area as compared with contributing areas covered by wheat or grass are shown in table 5. The plastic sheeting was laid in the fall of 1958 and is still in good condition. Patching was necessary in a few instances to repair damage by rodents.

TABLE 5.—Yields of wheat on benches with various contributing areas, 1959-61

Contributing area cover	Water storage, harvest to seeding	Wheat yields on bench
	Inches	Bu. /acre
Plastic	4.01	25.5
Grass	3.64	21.0
Wheat	3.01	18.8

Similar results were obtained at the Southwestern Great Plains Field Station, Bushland, Tex., where plastic watersheds were installed above level basins 54 feet by 95 feet. The first rain of any consequence was accompanied by hail that damaged the plastic sheets. However, in spite of hail damage, a watershed equal in size to the plot area produced runoff to increase the stored soil moisture 3.1 times the soil moisture

check plot. When evapotranspiration was accounted for it was apparent that almost 100 percent of the rain that fell in a 2-week period ran off the plastic watershed.

Another use of ground covers is indicated by experiments in Ohio. It was found that where surface water is in short supply, runoff can be substantially increased by covering the land surface with thin (0.004 - 0.006 inch) pliable plastic sheets. In one season, May through September, runoff from a plastic-covered cornland area in Ohio totaled 14.7 inches as compared with 3.3 inches from similar cornland without the plastic cover. The plastic was destroyed at corn harvest, but the possibility of developing mechanical means of reclaiming and reusing such materials appears likely.

Experience in application and maintenance of plastic strips over field-size areas is very limited; provision must be made for handling large rates and amounts of runoff water from major storms; durability of materials exposed to different climates are not known; and effect of plastic cover on reduced ground-water recharge is not yet evaluated.

Plastic material is available in sheets up to 32 by 1,000 feet. Materials that cost 1.6 cents per square foot would total about $700 per acre. The cost of plastic film varies, but the prices usually quoted range from 2 to 6 cents per square foot, depending on the thickness required.

Cutback asphalt emulsified in water and sprayed on soil to increase runoff from rainfall was not successful for the one experiment tried in Texas. The asphalt provided a good ground cover for less than one month. The thickness of the film seemed to have little influence on the durability. The soil of the test site cracks very badly upon drying. The particle size distribution of the topsoil at the site is sand, 39.16 percent; silt, 31.59 percent; and clay, 29.25 percent. Failure of the asphalt film appeared to be due to failure of the soil under the film rather than to failure of the asphalt. Soil adhered to the underside of the film after movement by the wind. More research is needed to determine proper methods of preparing land and installing the film. Cost ranges from $150 to $300 per acre covered and depends on the thickness of the film laid down.

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Recharge Underground Reservoirs

Recharge of ground water supplies is a growing practice. A major problem occurring in many areas is the desilting and clarification of water—by flocculants, algicides, and bacteriocides—that is to be put underground either by surface spreading or through injection wells. Injection wells are particularly vulnerable to sealing by silty waters and bacterial slimes.

Water Treatment

Results from experiments in Texas and California indicate that flocculants, described as nontoxic, synthetic, organic materials, will reduce silt plus clay content of the water. On one lake in Texas, a flocculant was applied by a crop-dusting airplane. The silt plus clay content of the lake water was reduced 93 percent after 1 day. The effect lasted for about 3 days. In other tests on other lakes the flocculant removed 40 to 90 percent of the silt plus clay content. Desilting tests by the Los Angeles Department of Water and Power were accomplished at a cost of $1.50 per acre-foot of water treated.

Algicides and bacteriocides are at present used only slightly in recharge operation, primarily because of the costs. In some instances where the costs are justified, water is chlorinated as it goes into injection wells. Chlorination has proved feasible and has aided in maintaining injection rates.

Soil Treatment

There is no great use at present of flocculants and soil stabilizers, although greater uses can be visualized in recharge operations. Practically all the use so far has been on experimental ponds.

The chemicals tested in laboratory and field were Krilium, Orzan, ferric sulfate, sulfuric acid, and gypsum. No cost-benefit ratios were established. These treatments can vary from below one hundred to a few hundred dollars in cost per acre. The materials tested have been only slightly to appreciably effective for water infiltration, depending on chemical material, soil characteristics, and methods of application.

Organic residues have been effective in promoting soil structure and stability of structure and permeability. Although an organic residue like cotton gin trash has been available at no cost to the farmer, the cost of picking up, trucking, spreading, and

disking the trash has amounted to $100 per acre treated. Other organic materials may be available as the result of vegetation grown; costs for use as a soil treatment would largely be associated with the incorporation of the material in the soil and wetting and drying.

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Re-Use of Waste Water

Several processes are in the development stage for re-use of waste waters. The electric membrane process has possibilities. It can reduce brackish waters to concentration levels of salt suitable for domestic or irrigation use. The cation-anion exchange is suitable for domestic or irrigation use. The cation-anion exchange resins will remove ionized waste materials and is used for this purpose to some extent.

A process for the removal of toxic concentrations of boron from irrigation water is needed. Certain types of exchange resins will do this, but the process is not economically feasible. Coagulants and chelating agents have been studied with only indifferent success.

Evaporation Control From Water Surfaces

Evaporation from lakes and reservoirs has been recognized as a major source of water loss. It is natural, therefore, that a considerable amount of research has been directed toward reducing this evaporation.

To eliminate losses due to both seepage and evaporation, water can be stored in a watertight bag, a recent development. Both butyl and plastic film can be used, but butyl is much superior because of its excellent aging properties. Storage of water in bags probably would not be practical for large bodies of water, but plastic and butyl could be used to cover small reservoirs. The use of pipe or tubing in the place of open channels likewise eliminates evaporation as well as seepage losses.

Considerable control of evaporation can be obtained with floating film covers. Work by ARS personnel on this approach is limited, but this research does demonstrate

that a very substantial saving can be effected. One of the problems has been to keep the film from wrinkling and sinking in places. Laboratory tests indicate this can be solved by using a foamed polyethylene, density 0.61, and a quilted structure containing cells of captured air. In these same laboratory studies, it was found that the reduction in evaporation resulting from floating covers was approximately equal to the fraction of the water surface covered. An example of the results obtained is illustrated in figure 5. Cov-

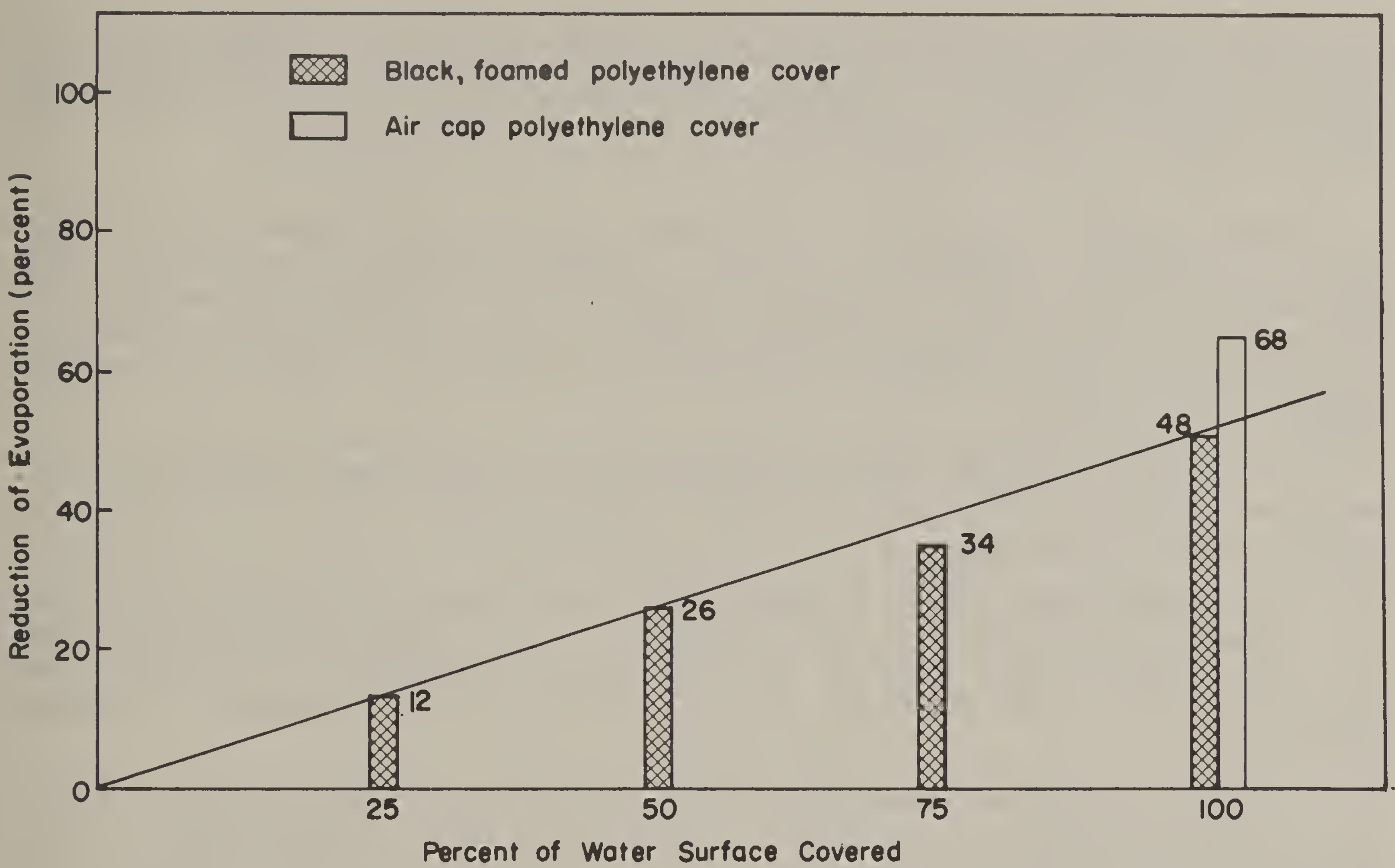

FIGURE 5.--Evaporation control with floating film covers.

ering the water surface completely did not prevent evaporation completely. If the film were sealed to the sides of the container, 100-percent control from evaporation would be expected, as is obtained when a bag is used for storage. The temperature of the water was higher where it was covered, as would be expected.

It is possible that evaporation could be controlled on rather large bodies of water through the use of multiple small floating covers. If opaque film is used, the film will control aquatic vegetation that often is objectionable, in addition to controlling evaporation.

It has long been known that certain chemical compounds, when applied to water surfaces, are capable of reducing the amount of water lost through evaporation. Until early in the 1950's, however, this knowledge remained more or less a laboratory curiosity. In more recent years attention has been focused on the possible use of chemical applications to ponds and large lakes.

The chemicals that have been studied for such use are those which form layers one molecule thick, called monomolecular films or monolayers, on a water surface and which also have the unique ability to reduce evaporation of the water. Among the materials that can form evaporation-reducing layers are the normal long-reducing layers and the normal long-chain alcohols, such as hexadecanol, which are insoluble in water, and waxlike solids or liquids.

In 1958, the U. S. Bureau of Reclamation together with several other organizations conducted the first large-scale field tests at 2, 500-acre Lake Hefner near Oklahoma City. The Oklahoma Agricultural Experiment Station initiated a research project in 1956 designed to provide data on the effectiveness of chemical films for evaporation suppression on reservoirs of a size found on most farms and ranches.21/

Three methods of application were tested. An experimental apparatus was developed for continuous application of a slurry of water and powdered hexadecanol. With this system it was possible to maintain a chemical film on the experimental ponds for prolonged test periods. Evaporation was reduced by 25 percent during a 66-day test. Intermittent applications for only 12 hours per day resulted in a reduction of only 6.5 percent in evaporation.

An economical analysis to determine the cost of saving water by evaporation retardation during an 11-day period of typical August weather showed the cost to be 89 cents per thousand gallons.

Windbreaks constructed of growing trees, shrubs, and materials such as posts and slat fences have possibilities of very wide use in the agricultural area of the Great Plains for reducing wind velocities. Less wind in turn results in less evaporation from water and soil surfaces. Windbreaks also increase ground water supplies by trapping drifting snow.

Windbreaks may be constructed of one or more rows of trees and shrubs. Artificial barriers may also be constructed of one or more rows. Effective wind reduction and spreading of trapped snow over the widest crop area require the windbreaks and barriers to have height and also a top-bottom row-density of about 3 to 1. This permits diffusion of the wind through the more open lower half of the structures and a braking effect on the wind by the more dense top half, which with height gives the long range protection.

A comparison was made of the evaporation over a 3-year period from a water tank located in an open field with that from one located in the shelter of buildings and trees. Evaporation was 35 percent greater from the open tank.

Soil moisture measurements at the Mandan station (N. Dak.) show that windbreak structures will trap drifting snow to an extent that the resultant snow-melt water will replenish moisture to field capacity in the first 6 feet or more of soil that was at the wilting point the previous fall. Windbreaks and erected structures are good for many years and will repeat the soil moisture buildup each winter when blowing snow is available.

The chief limitation of tree windbreaks is their competition with crops, thereby taking considerable land out of production in addition to the space occupied by the trees

21/ Crow, F. R. Reducing reservoir evaporation. Agr. Engin. 42(5): 240-243. 1961.

themselves. Both windbreaks and artificial structures have the effect of cutting large fields into smaller ones, which is objectionable to some farmers.

Windbreaks cost approximately $30 per mile of single row for tree stock and planting operations. Artificial barriers of post and slat fence material cost approximately $1 per foot for an 8-foot height.

The shape of a reservoir or pond could also influence the evaporation. Usually the topography controls the shape of the pond. However, it is known that narrow and deep reservoirs or ponds are more efficient than larger shallow ponds of the same capacity.

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Methods and Equipment to Measure Sedimentation

Sediment that originates from erosion decreases storage capacity as it collects in ponds and reservoirs. Movement and deposition of sediment across fields, in natural channels, and as sediment collects in storage units are under intensive study.

Several relatively new materials and equipment have been adapted to sediment research. These are radioactive isotopes for tracing sediment, gamma ray probe for sediment density determination, slow neutron probe for moisture determination, sonic depth sounder to monitor water surface and streambed profiles simultaneously, tritium for ground water studies, and carbon-14 for sediment dating. With the exception of the sonic depth sounder, all have radiation hazards that must be guarded against. The hazards are not considered particularly dangerous, but care must be exercised. The costs of materials and equipment are generally quite high and the sources limited and strictly controlled, as is proper. The materials, however, offer new avenues for research that promise great possibilities.

One of the newer developments is the gamma ray probe used for sedimentation surveys of reservoirs. This probe uses a radioactive source, radium 226, and Geiger-Mueller tubes, to indicate the density of the water-solids mixture of which reservoir sediment is composed. Wet volume-weights thus obtained can be converted to dry volume-weights, generally expressed as pounds per cubic foot. Dry volume-weights of reservoir sediment are required if reservoir sediment is to be related to, and compared with, erosion on the watershed.

The various parts of this apparatus are shown in the accompanying photograph (fig. 6). It is shown in use in the other photograph (fig. 7). The cost of this probe and its accessories is over $4,000. Cost of boats, motors, cranes, fathometer, and other apparatus required for using the probe totals a similar amount.

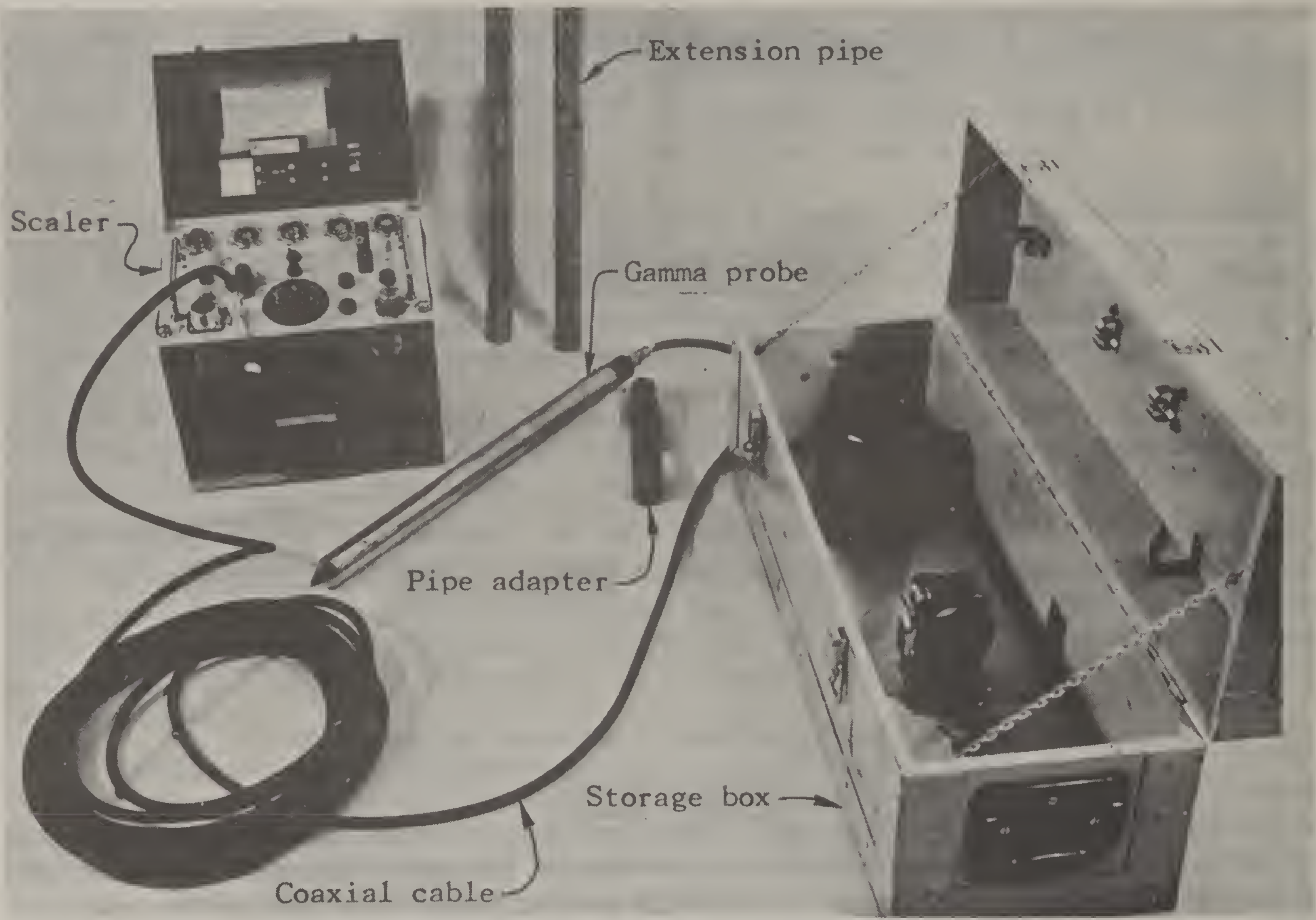

FIGURE 6.–Gamma ray probe used for sedimentation surveys.

The sonic depth sounder was developed for the Agricultural Research Service to monitor simultaneously water surface and streambed profiles under dynamic conditions in an alluvial channel. The stream monitor is a portable, fully transistorized instrument that uses the echo-ranging principle to determine distances to reflecting surfaces.

Two piezoelectric transducers are used as the sensing elements. The recorder is a spring-operated, dual-channel recording millimeter. The instrument is designed to operate at depths between 0.2 and 4 feet. The maximum depth from the sensing unit is 6 feet so that greater depths may be sounded by lowering the transducer a predetermined distance below the water surface.

The cost of the dual-channel stream sounder complete with probe-mounted transducers is about $1,900. Since this is a special instrument, the price will probably

FIGURE 7.–Using gamma ray probe to determine density of water-solid mixture in reservoir.

decrease as the demand increases. The recorder is a standard one, costing approximately $1,000.

Reduction of Losses From Storage and Conveyance

A continuous search has been underway to find economical and practical materials and methods for retarding seepage from storage and conveyance structures.

Soil Sealants

Exhaustive field testing at the U. S. Water Conservation Laboratory at Tempe, Ariz., has shown that cationic asphalts effectively reduce seepage from reservoirs and conveyance channels when 1 gallon per square yard is applied either by spraying on the soil surface or by pouring into ponded water where the emulsion disperses in the water and then plates out on the soil surface. The asphalt treatments should be useful in reservoirs, but they do not withstand erosive forces of flowing water and are probably not

practical in conveyance channels. The cationic asphalt emulsions have remarkable properties for bonding dissimilar materials and are now being tested in conjunction with reinforcing fabrics. The cost of cationic emulsions containing 5.5 pounds of asphalt per gallon should be about 25 cents per gallon.

SS-13 is a commercially available emulsified compound designed to be added to ponded water, where it is carried into the soil with the seeping water. The material contains resinous polymers that react in the soil to form a lattice of long chain molecules, which restricts water movement.

Laboratory tests have been conducted in soil columns to show that the SS-13 material penetrates sandy loam soils at least 4 inches below the soil surface and thus greatly reduces permeability of water in this treated soil zone. Laboratory and field tests have shown that the material will reduce seepage by over 70 percent under favorable soil conditions. Field tests conducted by the Bureau of Reclamation at the Salt River Project in Arizona and by the manufacturers of SS-13 have shown that the material remains effective for more than 3 years if it is not subjected to drying.

The toxicity of this material other than that associated with the use of diesel oil as a part of the emulsion complex does not appear to be a problem. The material has been fed to cattle and has been consumed by humans with no ill effects. Field tests have shown that the effectiveness of the material is essentially destroyed by alternate periods of wetting and drying. This problem has not been well defined and is currently under investigation.

The cost of material is dependent upon the ratio of volume to wetted perimeter in the channel or reservoir to be treated. SS-13 costs about $1 per gallon and is applied at a rate of about 1,000 parts per million in the ponded water.

Water Repellants

Many chemical compounds will effectively make soil water repellant. These include silicones, various combinations of salts and soaps, and other materials such as quaternary ammonium salts. The reaction of these materials can be simply explained by saying that the molecule has a head which is attracted to the soil particle and a tail that is repellant to water.

A number of compounds have been tested at the U. S. Water Conservation Laboratory, Tempe, Ariz. It has been found that the problem of making soils water repellant is not difficult. Effectiveness of a given chemical does vary with soil type, however, and it is necessary to conduct testing on each soil to determine the best material and the optimum rate of application for use. A small field plot sprayed with a water repellant, with no other treatment, has consistently produced from 40 to 60 percent runoff of rainfall. The water repellants can be sprayed on the surface of soil that has been previously treated with an asphalt emulsion to stabilize the soil against erosion. Large field plots treated with both the asphalt emulsion and the water repellant have produced runoff ranging from 80 percent to over 90 percent, depending upon quantity and intensity of rainfall.

Toxicity is not expected to be a problem with the use of the water repellants, but it must be considered and is currently under investigation. Some of the water repellent chemicals do deteriorate under continued high temperature, whereas others do not.

Selection of a water repellant will therefore depend upon climatic as well as soil conditions.

The cost of water repellants tested to date varies from about 45 cents to $1 per pound. The rate of application required to waterproof the soil has ranged from 20 to 500 pounds per acre. The rate of application depends primarily upon the soil, as it takes less for sands than for clays. Water repellants are already competitive on the market, and it is doubtful that costs will be greatly reduced by increased demand.

Studies of leaking ponds in the Ozark region of Missouri indicate that chemical soil dispersants, such as some polyphosphates, will reduce seepage in ponds constructed in coarsely aggregated clay soils. Chelating resins may be even more effective in forming polyvalent cation complexes, thus dispersing the clay colloids through destruction of the aggregate bonds. Provision must be made for bed strength beneath the dispersed layer to prevent "blowout" failures. Studies with soils from leaking ponds in Missouri indicate that mechanical dispersion, such as by the trampling of animals, is very effective in reducing seepage. Machinery to tread and disperse the soil beneath the water in ponds so as to produce a compact subsurface layer beneath a dispersed seal may be about as satisfactory from the standpoint of effectiveness and more economical than chemical treatments or sheet membrane liners.

Linings

Considerable research on the development of lining for controlling seepage has been conducted at Logan, Utah. This work has included:

- Earth material of several types—used both as blankets and as waterborne sediments.
- Earth stabilized with chemicals—applied to the subgrade as sprays and mixed with the subgrade material or as specially imported earth material to form a stabilized and waterproof lining.
- Earth stabilized with portland cement; that is, soil cement.
- Earth stabilized with cutback asphalt and asphalt emulsion.
- Asphaltic membranes—both buried and exposed.
- Prefabricated asphalt liners, for use both as buried and exposed membranes.
- Asphaltic concrete.
- Prefabricated liners consisting of plastic-coated paper and paper cloth, resin impregnated paper, and similar materials.
- Portland cement concrete and shotcrete.
- Plastic films, such as polyethylene, vinyls, mylar—buried and exposed.
- Rubber, such as butyl, neoprene, polyisobutylene.

Many of these materials cannot be classified as new, but the methods developed for their use frequently were new or the material was modified for better adaptation to the use under consideration. Any of the linings or treatments, except for cleaning or enlargement, tend to reduce seepage. Working or compacting the subgrade will reduce seepage to a degree, depending on the operation. If the subgrade material is gravel, a topping of sand will reduce seepage. Complete watertightness is seldom achieved. Of all the lining material mentioned, butyl sheeting (fig. 8), plastic film, and prefabricated liners (fig. 9) are the most watertight, and even these cannot be depended upon to be fully watertight, owing to the possibility of damage during installation and faulty joints. Site conditions and other factors, including canal and reservoir management practices and cost, determine the type of lining that should be used. Materials such as butyl and plastic, in particular, appear to have great potential as liners.

Results to date indicate linings may be classified into four groups with the following benefits and limitations:

(1) Paved or hard-surfaced linings.

Materials: Concrete, brick.

Benefits and limitations: Prevents seepage, scour, and controls weeds; requires little maintenance; permits wider range of velocities; resists damage from livestock and equipment.

(2) Exposed membrane linings.

Materials: Exposed asphalt lining.

Benefits and limitations: Prevents seepage and controls weeds to a degree; treatment with fungicide chemicals necessary; must be cleaned with care; not suitable where subject to heavy animal traffic.

(3) Conditioned earth linings.

Materials: Natural earth compacted; earth stabilized with chemicals, with small amounts of asphalt, or with small amounts of portland cement.

Benefits and limitations: Controls seepage but weed problem is same as in unlined canal; frequently subject to scour unless protected with nonerosive topping such as gravel; cheap to construct under ideal conditions; velocities of water flow limited to 3 ft./sec.; protective cover desirable.

(4) Buried membrane linings.

Materials: Asphalt and plastic membranes.

Benefits and limitations: Controls seepage but frequently adds to weed problem and the care must be used in cleaning; velocities of water flow limited to 3 ft./sec.

Although most studies to control seepage have been conducted in the West, three plastic pond liners have been installed in Virginia. The dark-colored vinyl film used in these tests was manufactured with a plasticizer not affected by fungus.

FIGURE 8.—Laying out 15-gage butyl lining during construction. The lining will be buried and covered with earth material for protection.

FIGURE 9.—Asphalt-coated jute liner on a farm irrigation canal.

These preliminary studies in Virginia indicate that the vinyl liners for ponds must be installed on smooth surface areas. On unstable areas where voids are likely to occur, special reinforcement methods must be worked out. Maintenance will be needed where wave action and ice cause problems at the water's edge. This calls for a protective cover of soil, sand, or stone over the liner, and this cover may need to be replaced periodically.

Cost of the vinyl liner is about 30 cents per square yard, or about $1,450 for enough material to cover a one-acre pond.

Material is available from many sources and should continue to be available at the above price.

Membranes for Cutoff Walls, Inflatable Dams, and Related Control Devices

Plastic film has been used as a curtain wall to control seepage from canals and through earth dams. Control can be effected in this way, particularly if the film can be carried deep enough to intercept a profile with low permeability. Even when this can't be done, the flow length is increased and some control is effected.

When heavier soil materials are used in constructing the dam, they have a tendency to crack upon drying. In small earth reservoirs that dry up periodically, the use of butyl sheeting or plastic film buried in the dam structure does two things: (1) It makes possible the use of relatively porous materials, and (2) provides good insurance against breaching before cracks have time to seal. Although no tests have been conducted, it appears the membranes—particularly the heavier gage butyl sheet—could well be used to advantage as a substitute for the core to obtain watertightness, and thereby effect great savings by removing the necessity of importing selected earth materials.

Plastic dams have long been used advantageously as a substitute for canvas dams. The excellent durability of butyl makes checks and diversion structures of this material well adapted to structures of this type. A butyl diversion structure could well take the place of concrete structure. It would be inexpensive, removable and reusable, quick to install, completely watertight, and it can be connected to gated pipe or tubing. However, shoots of vigorous perennial weeds such as johnsongrass, nutgrass, and woody plants may rupture the lining. Chemical treatments to eliminate these weeds and the application of soil sterilant herbicides before installation of the linings has partially solved the problem.

Water control on ricefields is also an important problem for the agricultural engineer. The earth levee has been the standard structure for maintaining uniform depth and control of flooding water. Studies were made on ten ricefields in the area around Biggs, Calif., by the University of California. These fields ranged from 40 to 400 acres in area, the average being 181.2 acres. The area devoted to levees averaged 7.4 acres (3.8 percent) per field, the equivalent of 205 feet of 8-foot levees per acre. Such levees are costly to construct and to maintain. Serious weed growths develop on the levees and harvesting around the levees is so difficult that grain losses are high.

Preliminary studies on the use of plastic film levees have been conducted at Biggs, Calif., and Beaumont, Tex. It appears that they have these possible advantages:

- Require a minimum of land area.
- Will not support weed growth.
- Permit harvesting large areas because plastic levees can be removed before harvest.
- May eliminate or reduce the large levee-forming equipment.

A few of the problems yet to be solved in this application include:

- Selection of a plastic formulation that can fully resist prolonged exposure to sun and temperature variations.
- Development of an improved method of supporting the film on stakes.
- Mechanization of both the placement and removal operations.
- Development of a levee with a wire, nylon, or fiberglass cord embedded in the top ridge that would aid in applying tension to hold up the film. Thinner, lower cost films might be utilized with this type of support.

There is little doubt that the placement and pickup of these plastic levees can be fully mechanized. Based on 205 feet of levee per acre and careful estimates of material, stake, and labor costs, the University studies showed an annual installation and removal cost of the plastic levee as $14.39 per acre. Similar studies showed that the cost of constructing, maintaining, and removing conventional earth levees was $6.01 per acre.

Saving in harvesttime through removal of the levee was estimated to be one-half the harvest cost, or $4.34 per acre. Based on the area of land that is returned to rice production when earth levees are replaced by the plastic levee, the studies showed an additional $4 return from the land so returned to production. It was estimated that approximately two sacks of rice per acre may be gained if a plastic levee is used to replace the soil levee, because the weed-seed population once eliminated by spraying or tillage may possibly be reduced by half. This contributes an additional $8 return per acre.

The University summarized the economics of the situation by comparing the cost of 4-mil black polyethylene film, stakes, and manual installation at $14.39 per acre with the approximate cost that could be spent on such a levee. This figure is the sum of the following items:

	Cost
Per acre production from land formerly occupied by earth levees---	$4.00
Per acre savings on harvest costs----------------------------------	4.34
Per acre cost of soil levee construction--------------------------	6.01
Per acre savings from weed damage-------------------------------	8.00
Total ---	$22.35

Hence $22.35 less $14.39 results in a profit of $7.96, or approximately $8.00 per acre, or about 8 percent increase in gross income.

Tubing

Relatively rigid plastic, aluminum, asbestos cement, bituminous, or steel tubing has been used successfully for a number of years. However, continuous search is being made for new materials to fill the need for durable and flexible tubing for irrigation purposes.

The largest single farm use of polyethylene resins has been in the form of plastic water pipe. This pipe, when less than 2 inches in diameter, is shipped in coils. The larger diameters are shipped in straight pieces. The smaller diameters can be installed with a pipe layer attached to a conventional tractor. Many miles of plastic pipe have been used for delivering water to plantbeds, livestock tanks, and small irrigated areas that are a considerable distance from a water supply. Some high-density resin is now being used in this pipe application.

"Lay-flat" or low-pressure flexible tubing, another type of plastic pipe or tubing, is also gaining in demand. Made largely of black polyethylene, it is available in diameters from 2 to 18 inches. Film thickness varies from 8 to 20 mils, depending on size and operating heads. These tubes may either be continuous for transporting water, or may be equipped with grommets or plastic sleeves spaced at intervals for discharging water into individual furrows.

Studies are underway at several locations on the use of large-diameter (up to 36 in.) flexible tubes (fig. 10). These tubes are constructed from two or more layers of plastic between which is sandwiched a reinforcing fabric of nylon, fiberglass, or other high tensile strength fibers. Polyethylene, vinyl, butyl, and other materials are being tested for this use. In these large diameters a very effective low head, high-volume water transmission tube can be effected. Note the advantages: no seepage loss, no evaporation loss, no loss to phreatophytes, excellent hydraulic characteristics, and a minimum of earth moving to provide a base. Some of the disadvantages are restricted heads, and liability to puncture or damage by rocks, bullets, or animals. Some of the early problems of separation and blisters forming between the layers seem to have been solved.

A full evaluation of cost and hydraulic characteristics of large-diameter lay-flat tubes is being developed by the ARS at Utah State University. Preliminary results indicate that with further development these tubes will become an important item in irrigation water transmission systems.

Pipe

Plastic pipe of large diameters is becoming more and more common for irrigation pipe lines. The use of concrete continues and the developments in this field consist of improved methods of installation. Cast-in-place concrete pipe has proved successful at a number of locations. The procedures are patented and result in a continuous pipe with no joints (No-joint and Fullerform). Outlets, elbows, and other fittings can be installed wherever needed.

FIGURE 10.—Thirty-six-inch diameter lay-flat tubing used to convey water over porous areas without loss by seepage.

Phreatophytes and Aquatic Weed Control

Solution of the phreatophyte problem necessitates elimination or control of heavy-water-using phreatophytes. Their elimination or control with present methods is extremely difficult and expensive. Chemical control has not been explored adequately. For instance, no one-spray treatment with the common brush killer chemicals will kill saltcedar.

Since 1950, chemical methods have largely replaced mechanical methods in controlling aquatic and bank weeds in and along irrigation and drainage channels and farm ponds. The chemical methods usually are more effective, more convenient, less time consuming, and often less expensive.

In canals with capacities of 70 cubic feet per second or less, control of submersed weeds with aromatic solvents or acrylaldehyde (acrolein) is less expensive than mechanical methods. In larger canals with capacities up to 200 c.f.s. and where sprinkler

irrigation is extensively practiced, chemical control is economical, as the aquatic weeds killed by the chemicals disintegrate slowly and do not cause clogging. Mechanical devices dislodge masses and fragments of aquatic weeds, which cause frequent clogging of the sprinkler heads, valves, and pumps. Recently, in the Columbia Basin of Washington, new techniques with xylene have controlled submersed waterweeds in canals with capacities as large as 300 to 500 c.f.s.

Cattails, tules, and other emersed weeds in channels and ponds are largely controlled either by 2, 4-D in oil-water emulsion, by amitrole, or by dalapon. Timely and regular use of these herbicides decreases the cost of controlling weeds and results in less frequent need for removing silt deposits by mechanical methods. The Bureau of Reclamation has reported[22/] that the average cost of chemical control of cattail ranges from $25 to $43 per mile of channels, as compared with $407 to $418 per mile for draglining.

Bank weeds and phreatophytes along channels, around ponds, and on flood plains can be controlled by 2, 4-D, silvex, or 2, 4, 5-T. Chemical methods usually are more convenient and effective than mechanical methods. However, mowing, burning, and bulldozing often remove the vegetation more rapidly, are sometimes less expensive, and may be less hazardous to crops on nearby farmland. Nevertheless, the development of less expensive or more selective herbicides undoubtedly will extend the replacement of mechanical methods.

In areas where cotton, grapes, tomatoes, and other crops highly sensitive to 2, 4-D, silvex, 2, 4, 5-T, and other phenoxy-type herbicides are extensively grown, mechanical methods are better adapted than chemical methods. However, weedy grasses can be controlled by amitrol, dalapon, or aromatic or fortified weed oils in such areas.[23/]

Control of broadleaved weeds and brush along channels and around farm ponds by selective herbicides like 2,4-D, silvex, or 2,4,5-T has greatly aided the establishment of desirable low-growing grasses for stabilizing banks and preventing erosion and sloughing. The dense stands of grasses also prevent or reduce the encroachment of undesirable bank weeds. A recent study in Washington indicates that regular use of copper sulfate at frequent intervals to control algae in irrigation canals encouraged the spread of a dwarf species of water plantain, which competes with and eliminates or reduces the troublesome rank-growing pondweeds.

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Most irrigation and drainage channels are constructed to carry specific volumes of water, usually without adequate allowances for the effects of weeds. Weed growth and the resulting silt deposits reduce the volumes of flow in many channels much below the designed capacities. Chemical control of the weeds helps to restore the flow to designed capacities and to eliminate enlargement of channels to allow for expected weed growth.

Hand and mechanical methods of controlling such weeds usually require much more manpower than chemical methods. In areas and seasons of labor shortage, the saving in man-hours and the more efficient and rapid weed control by herbicides are important considerations aside from the relative costs. Considerable manpower and machinery are released for other work.

Effective herbicides now available that control submersed aquatic weeds are usually too expensive to use in canals larger than 200 c.f.s.

In recent laboratory and field experiments, several chemicals show promise of giving satisfactory control of submersed aquatic weeds for one or more years when applied to the bottom of the canals. Such chemicals might prove economical for use in large canals where submersed aquatic weeds are causing a threat to adequate and timely delivery of irrigation water.

As a result of extensive and intensive use of herbicides, the time for inspection and for cleaning clogged structures, removing weed jams, and repairing ditchbreaks and similar maintenance work was reduced in one area in California.24/ Even more important is the more adequate and timely delivery of irrigation water to crops and the more prompt drainage of excess water from farmland. With such chemicals as xylene and acrolein, properly applied, the treated water may be used for furrow irrigation without injury to crops.

Dependable weed control with herbicides in irrigation systems may eventually result in the acceptance of devices for automatic measuring and delivering of water, with a considerable saving in time now required for operating the turnout gates. The principal deterrent to this manpower-saving practice at present is the risk of clogging the measuring devices and automatic gates by floating weeds and the irregular flow of water caused by weed growth.

The general use of herbicides to control weeds has had important effects on the management of croplands. The more ample and regular supplies of irrigation water permits greater latitude in the choice of crops and cropping practices. In other areas, the more efficient drainage of excess water through weed-free drainage ditches also permits a wide choice of crops and cropping practices.

On the other hand, the differential tolerance of crops to herbicides used to control ditchbank weeds sometimes determines which crops may be safely grown adjacent to irrigation or drainage channels.

24/ Timmons, F. L. Profits from research on control of aquatic and ditchbank weeds on irrigation systems. West. Weed Control Conf. Proc. 16, pp. 41-46. 1958.

Consideration must also be given to crops that may be safely irrigated with water from canals or ponds treated with herbicides. The persistence and behavior of herbicides in irrigation, drainage, and impounded waters must be more thoroughly understood to insure safety for use by man and animals.

More complete and timely control of bank weeds along channels and around ponds by herbicides has, in some areas, eliminated or greatly reduced the production of weed seeds that may be carried to cropland by wind or irrigation water.

Irrigation Water Application

Improving the efficiency of irrigation has been the aim for many years in the U. S. Department of Agriculture. Water application efficiencies now range from 30 to 80 percent, with the average less than 50 percent. Improvements can come about by better management practices—proper land preparation, length of run, proper scheduling of irrigations according to time and quantity of water to satisfy the crop requirements, proper distribution systems to fit the farm layout and to fit the individual irrigated fields so as to supply adequate water in the time required and as indicated by the infiltration rate.

Losses from improper management practices are excessive after irrigation if water percolates below the root zone or if it runs at the lower end of the field.

When water is scarce and crop products are unusually valuable, as in some irrigated sections of the Southwest, the irrigator uses the available water with care and relatively high irrigation efficiencies are obtained. In such sections, large expenditures are justified in order to save water. In farming regions where crop returns do not warrant large expenditures in order to reduce losses and waste, irrigation water is often applied with low efficiencies. This is especially true in regions where large supplies of water are available. Another factor entering into efficiency of water application is the cost of labor. In some cases this cost outweighs the value of water saved by more efficient operations. Future design of irrigation systems and methods of irrigation must take this item into consideration if irrigation applications are to be improved.

Efficiency of irrigation water application may be affected by the infiltration rate of the soils. On sandy soils the infiltration rate may be excessive for good irrigation and on tight soils the infiltration may be too low to permit sufficient water to enter the root zone. The problem of infiltration, therefore, resolves itself into a reduction of infiltration rate or an improvement of infiltration rate, depending on the site conditions. Much research is going into the control of infiltration rates on irrigated lands, but at present there seems to be no economical materials available or method known.

Infiltration Reduction

Most data on reduction of infiltration rates have been developed for control of canal seepage and for the increase of precipitation runoff from water harvest areas. A need exists, however, for the reduction of infiltration on some irrigated soils.

Furrow irrigation on sandy soils is not practical under present conditions, because of the very high intake rate of water into the soil. Controlled reduction of the

intake rate so that the soil profile under reasonably long furrows will be wetted uniformly may be desirable. Water repellants of different kinds may be used to control intake rate. These would include asphalt emulsions, bituminous compounds, salts of fatty acids, and resinous compounds. The difficulty in the use of such materials would be in the control of the desired effect. Natural waterproofing materials often accumulate in sandy soils, so as to prove detrimental in reducing the water storage capacity. It should be added that such water repellant sands have become noticeably erosive.

Infiltration Improvement

Infiltration into tight soils may be improved by the use of soil stabilizers such as the polyacrylonitriles and other polymers. Some of these materials are quite effective in the soil layer treated. In deep, plastic clay soils, the mechanical difficulty of treating deep soil layers would pose problems. The cost of soil stabilizers at present makes their use on field soils of doubtful economic value.

Control of Evaporation From Soil

Large amounts of water are lost to the atmosphere by evaporation from soils. This is a nationwide problem and research is being done at several locations. In the West the prime concern is with evaporation during and after irrigation. In the Midwest and East the concern is with evaporation after rains.

Four States in the Northeast Branch have used polyethylene film for moisture control and for mulch, with good success. A thin polyethylene film only 1.5 mil thick does an adequate job of preventing surface evaporation (fig. 11).

Studies in New York showed that covering the soil with translucent plastic, which was slit to facilitate infiltration, increased available water as well as soil temperature early in the spring. Yields of corn in 1961 were increased by 16 bushels per acre for a normal-season hybrid, and by 35 bushels for a long-season hybrid. On one plot the plastic was sealed to the cornstalk to prevent rain entering the soil. This plot, located on the top of a hill, produced 113 bushels of corn on the estimated 7 to 8 inches of water that was stored in the soil at planting time.

In New Jersey black polyethylene film has been used to control surface evaporation in growing cantaloups. Tests have shown that there was enough moisture in the soil at field capacity to produce a crop of cantaloups. With black plastic film cover, the yields were as good as or better than where the melons were clean cultivated. Soil fertility measurements indicated less nutrient loss by leaching under the plastic.

In Virginia a study of moisture conservation measures showed that evaporation suppression by a plastic mulch was of greater benefit to tobacco than transpiration suppression by fog nozzles. There were no evaluations of relative humidities or soil moisture conditions to determine just how greatly conditions were altered by the different treatments.

In Maine clear and black polyethylene plastic mulches were used in connection with a study of soil temperature effects on potato growth. Neither polyethylene mulch significantly affected potato yields, but both polyethylene mulches gave an increase in soil moisture when used from planting until bloom time. The average daily temperature

FIGURE 11.–Evaporation control with polyethylene plastic film.

of the soil was raised 1° Fahrenheit by black plastic and 3.6° by clear plastic, as compared with bare soil.

Cost of the material used is around 4 cents per square yard, or less than $200 for enough material to cover an acre of ground.

Results of tests conducted at North Platte, Nebr., are indicative of the effects of plastic coverings under the dryland conditions of the central Great Plains. The material used was black, 6-mil, polyethylene plastic sheeting with low water transfer characteristics but fairly permeable to oxygen, nitrogen, and carbon dioxide gases. Preliminary field tests were conducted under dryland conditions with corn and grain sorghum in 1958 and with grain sorghum in 1959. Complete soil cover with plastic greatly reduced total water use by the plants and increased the efficiency of water use (table 6).

The complete plastic cover held evaporation losses to a minimum. Total water use in the plastic-covered treatments averaged about 46 percent of the noncovered check plots. It would appear that evaporation losses under dryland conditions in the central Great Plains are approximately 50 percent of the total water use during the cropping season.

TABLE 6.—Effect of plastic sheet cover on evaporation losses, total water use, crop yield, and water use efficiency, North Platte, Nebr., 1958-59

Crop, year, and treatment	Total water use	Grain yield	Water use efficiency
	Inches	Bu./acre	Bu./inch of water
1958			
Corn:			
No cover	13.53	66.4	4.91
100 percent plastic cover	6.25	62.8	10.05
Grain sorghum:			
No cover	13.45	65.1	4.84
100 percent plastic cover	5.27	78.0	14.80
1959			
Grain sorghum:			
No cover	16.84	87.2	5.18
100 percent plastic cover	8.98	104.0	11.58

Total yield of corn was slightly lower under the plastic cover, whereas the yield of grain sorghum increased 20 percent both years. This increase in sorghum yield may be in part the result from higher temperatures under the black plastic early in the growing season.

Water was used more than twice as efficiently by the crops in the plastic-covered plots as in the noncovered plots. Limitations of plastic cover under a wide variety of climatic conditions are not presently known. The possibility of plant disease factors occurring because of the change in microclimate under the cover should not be overlooked.

Cost of material used is approximately 12 cents per square foot. This cost limits extensive use except for high-value crops.

Laboratory studies at Mandan, N. Dak., were made to determine the effect of the percentage of surface covered with plastic on evaporation. A marked reduction in evaporation occurred as the percentage of the surface cover was increased.

It has been proposed that reduction of evapotranspiration on a regional basis may be difficult, if not impossible, because energy prevented from evaporating soil moisture by waterproofing will increase sensible heat and cause increased evapotranspiration from adjacent cropped areas. This would not be true if the increased reflection by the waterproofing material reflected a larger amount of the sun's energy than was used in evaporation on bare soil.

White, pigmented, polyethylene sheeting, 4 mils thick, has a high reflectivity index.

Sensible heat convected from the white plastic surfaces to the air was found to be less than 60 percent of the sensible heat convected from soil surfaces, despite the fact that considerable evaporation from the soil surface was taking place. Thus, white-colored polyethylene sheeting can dispose of unwanted energy from the sun by reflection, and regional reduction by evapotranspiration is definitely possible.

Unfortunately this particular plastic sheeting decomposes, becomes weakened, and lasts for one, or at the most, two cropping seasons.

At present this sheeting costs slightly more than 1 cent per square foot. Large-scale production and distribution could possibly cut this cost in half. Increasing the longevity appears to be the most promising method of decreasing the annual cost of this material. (Black polyethylene plastic has lasted for several years under similar conditions.)

Hexadecanol added to lakes or reservoirs reduces evaporation of water. It may have a similar effect on water stored in soil, but its effect in soil is unknown. Material tested at Fort Collins, Colo., was described as micronized n-hexadecanol. It was a mixture of hexadecanol and octadecanol, long-chain fatty alcohols used in the manufacture of some common detergents.

Evaporation of water from soil may be decreased by materials that reduce the surface tension of water and increase the angle of wetting between the liquid and the soil surfaces. Both of these changes reduce the capillary rise of water in soil. Under such conditions evaporation from the surface tends to form a dry layer of soil at the surface, creating a diffusional barrier to loss of water by evaporation.

Evaporation of water was reduced by adding hexadecanol to a soil placed in a greenhouse. Mixing the material with soil to a depth of 1/4 inch from the surface was the most effective placement, and mixing the hexadecanol with all the soil in the container was next best of four placements. The amount of water saved by the surface application was 18, 21, and 44 percent for rates of 1, 5, and 25 grams hexadecanol per 3,000 grams soil, respectively. The depth of soil in the container was 6 inches. These values are an average effect for a period of one year. The surface application treatment had not changed in effectiveness one year after application, but the hexadecanol mixed with the soil was only half as effective after one year as at the beginning.

The limitations of this material are cost and the decomposition in the soil. The main objective of this research was to determine whether hexadecanol changed certain properties of water in soil enough to reduce evaporation. More effective placements are quite probable, which would lower the rate of application and the rate of decomposition in the soil.

Cost of the hexadecanol is nearly 40 cents per pound. In liquid form the hexadecanol costs about one-half as much. In this study the lowest rate of application was 660 pounds per acre. Further research could lower this rate considerably.

Hexadecanol is available from various sources, particularly companies manufacturing detergents.

Other materials tested for reduction of evaporation from soils include the chemical dimythylactadecylammonium chloride (hereafter referred to as DDAC). It is sold under the trade name Arquad 2HT. The principal property of DDAC of interest here is

its effect on capillary movement of water in soils. Laboratory tests have shown that liquid water movement into a soil properly treated with DDAC is virtually stopped. Treatment of a soil with DDAC changes the treated soil from a water-absorbent to a water-repellent medium.

Complete treatment of the soil with DDAC is uneconomical. However, it has been found that partial treatment is quite effective. Since practical conservation of water involves getting the water into the soil as well as minimizing loss once it is there, the effect of DDAC on infiltration was also studied. Since liquid water movement occurs by similar mechanisms in evaporation and infiltration, the result, as would be expected, was reduced infiltration.

At present, practical methods of use have not been found because of limitations of the material. A DDAC-treated soil has less dry stability than an untreated soil and is therefore more subject to movement by wind in the field. The treated soil is effective only so long as the soil is air-dry. Since it is uneconomical to treat all the soil, water vapor can be absorbed within the treated soil, thus making it difficult, under field conditions, to keep the treated soil dry. A further limitation is that DDAC treatment not only decreases evaporation but also decreases infiltration.

According to the manufacturer, DDAC is a byproduct of the meatpacking industry and is available in large quantities. Very little cost reduction was foreseen as possible in the future. The cost of the material would amount to $25 per acre for a 0.1-percent treatment to the top 2 inches of soil.

Transpiration Reduction

This is a new field of investigation, and many questions about its effectiveness remain unanswered. Since evaporation from leaf surfaces is a cooling process, there is some question as to detrimental effects on the plant. The control of plant stomatal opening offers possibilities in moisture use efficiency and conservation.

The possibility that hexadecanol, which has been effective in reduction of evaporation from water surfaces, might also be used to suppress transpiration by plants was investigated. Hexadecanol and octadecanol (a material similar in properties, cost, and source of supply as hexadecanol) added to a soil in which corn was grown in a greenhouse failed to decrease the amount of water used per unit of dry matter. Both alcohols reduced the yield of corn significantly when they were mixed with the soil at the rate of 25 grams per 3 kilograms of soil. Considerable decomposition of the added alcohols had occurred during nearly 2 months of exposure to the soil. The alcohol could not be recovered from the soil receiving 1-gram treatments per pot.

Other proposals are to spray plastic latex-type emulsions on growing plants to reduce transpiration losses. Preliminary field trials with grain sorghum were inconclusive. Additional well-planned trials are warranted, using several materials as transpiration depressants and studying the concentration to use; stage of growth to apply; toxicity, if any; persistence of film; action on transpiration; and effect on moisture conservation and its efficient use.

Automation for Irrigation Control

Recent developments by the ARS for better irrigation water control are the automatic and semiautomatic gates. These are constructed of galvanized steel, steel, and

copper combined with Neoprene and butyl rubber sealing strips. The gates are self-operating and control the delivery of water from irrigation ditches to the land.

Costs are not available and the gates are as yet not available commercially.

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Drainage

The practice of the art of drainage is probably as old as the art of agriculture. The first recorded examples occurred during the time of the Roman Empire. Methods of drainage have not varied greatly in the last 100 years when tile drainage was first introduced. There has been, however, a constant search to improve subsurface and surface drainage facilities, to discover more economical materials, and to discover practical methods and materials to extend the effective life of drains.

<u>Mole Channel Lining</u>

Mole drainage is an old practice but has not been very effective, except in a few areas, in the United States. The principal advantage of mole drainage is its low initial cost. At a depth of 30 inches and with drains spaced 20 feet apart, it is estimated that the cost is less than one-tenth of that for tile drainage. The chief disadvantage of mole drainage is its short life in most soils. In order to impart longer life to mole drains,

attempts are being made to line them with plastic materials. The lining implement is pulled behind the mole plow and allows a continuous roll of plastic to feed into and form in place within the mole drain. Operating depths depend on the power available, but, the depth is usually limited to 24 to 30 inches.

The lining material comes in rolls 11 inches wide, 500 feet to a roll. The material is made of different types of plastic as follows:

- Polyvinyl chloride
- High density polyethylene
- Styrene copolymer
- Rhyco "Quick Set"

The polyvinyl chloride is the only type of material that has been used in any quantity. Various sizes, shapes, and configurations of polyvinyl chloride have been tested in the field as follows:

- 11 inches wide, 0.015-inch thick, lap-sealed with pressure tape
- 11 inches wide, 0.014-inch thick with 1 inch slits and a 3-inch overlap
- 6 inches wide, 0.015-inch thick arch with 4-inch wide, 0.004-inch thick floor cemented together with 1-2 dichloroethane solvent
- 6 inches wide, 0.015-inch thick arch without floor
- 8 inches wide, 0.018-inch thick with zipper lap.

A polyethylene, thick-walled "drainage pipe" also is available. This is a 2-inch-diameter continuous pipe with 1/8-inch wall thickness that has 1/4-inch hole perforations at 2-inch centers along the bottom fourth of the pipe sides. This material comes flattened out in 200-foot rolls.

Little or no actual commercial installation of plastic liners has been made. Almost all the usage to date has been in field trials at Cornell University, New York State; Gainsville, Ga.; Jacksonville, Fla.; Baton Rouge, La.; Grand Junction, Colo.; Logan, Utah; Fallon, Nev.; Halfmoon Bay, Firebaugh, and Panoche, Calif.

The use of plastic liners is still in the experimental stage. Most, if not all of the plastic materials, are relatively inert and do not disintegrate except when exposed to sunlight. The thin-walled plastic liners have little or no bearing strength. Thick-walled plastics have bearing strengths of 100 to 200 pounds per foot, depending on wall thickness and diameter.

Cooperative studies between the Agricultural Research Service, Cornell University, the Caterpillar Tractor Co., and the Union Carbide Plastics Co. have outlined methods and principles that are at present being developed and improved. With further improvement in equipment, grade control devices, and plastics, it seems more than probable that line channels 3 inches in diameter and at depths of 42 to 48 inches can be achieved (fig. 12).

FIGURE 12.–Mole plow used for installing low-cost plastic liner. The liner–15 mil perforated semirigid vinyl plastic sheeting–is on flat spool shown on top of plow. The edges are die-cut so they can be "zipped up" as sheet is formed into liner.

A detailed study of the loading characteristics of plastic-lined mole drains showed that thin-walled materials (0.010 to 0.030 inch) have little influence on the stability of the drain under surface loads. The arching action of the soil was the main factor determining the drains' resistance to deformation by surface loads. Further studies of soil mechanics must be undertaken.

Present experience shows that a 3-inch-diameter lined channel can be installed up to 28 inches in depth for about 10 cents per lineal foot.

Dug-Ditch Subsurface Drains

Clay and concrete drain tile are by far the most widely used materials for subsurface drainage. For efficient operation and long-effective life of these drains, recent

attention has been given to the use of new materials to act as filters or stabilizing mats to keep soil out of the tile lines.

Fiberglass Tile-Gard is used extensively to prevent tile clogging in silty and sandy soils. Some States reporting its use are Michigan, Indiana, North Carolina, Florida, Washington, Maryland, and California.

In the usual installation, Tile-Gard, placed on a special attachment behind the trenching machine, is unrolled as the machine progresses and covers the top and sides of the drain tile. However, in some instances the tile is completely encased in Tile-Gard. Sometimes a nonporous stabilizing mat is used under the tile.

Fiberglass (Tile-Gard) is an inert porous mat about 20 mils in thickness composed of multiple layers of lime borosilicate glass filaments in jack straw arrangement and is held together with a binding agent of phenol-formaldehyde. Tensile strength is provided by reinforcing the mat with fiberglass yarn in a swirl pattern. The average weight is 1.2 pounds per 100 square feet. It is available in rolls of 12-, 16-, 20-, 24-, and 36-inch widths.

In a comparison of a number of filter materials, (1) fiberglass with plastic, (2) straw, and (3) sawdust, in that order, provided the best protection against soil movement into tile lines. Gravel, 270-degree-wrap fiberglass, and topsoil ranked fourth, fifth, and sixth, respectively.

Other research on fiberglass mat was conducted by the Agricultural Research Service with two fiberglass sheet materials, one containing longitudinal reinforcing and the other an improved material with random reinforcing, to determine their suitability for use as filter materials for tile drains.

The original material with only longitudinal reinforcing was generally unsatisfactory, whereas the improved fiberglass performed satisfactorily. For the improved material a criterion was established for determining what soils can be prevented from entering a drain. The criterion when compared with available data shows that the improved fiberglass material will function satisfactorily in most unstable soils. Under limited tests there has been no indication of clogging or sealing of the fiberglass.

A cursory examination of fiberglass strength in withstanding impact loadings during machine backfilling indicates that from 2 to 4 inches of soil must be placed over the sheet manually in order to insure against tearing and breaking the material. If these precautions are exercised, use of the fiberglass material can result in reduced installation costs and thereby effect greater economy in the drainage of agricultural land.

Ohio State University completed tests of fiberglass filter material with the following results: The average of three tests running for 88 days showed the silt accumulation in the bare tile to be 3.49 times greater than in the filter-protected tile. The rate of discharge from the fiberglass-protected lines was 1.70 times greater than that from the bare tile lines. (The average of the first three tests had 75 percent of the joint space protected.) Each cubic foot of water entering the bare tile lines contained 7 times more silt than a cubic foot of water from the fiber-protected line.

In one test, the filter was completely wrapped around the tile for one plot. The other plot had bare joints. In this test the filter gave almost complete protection against silting. The discharge from the filter-equipped plot was 2.26 times greater than from the bare-tile plot in this test.

Cost of the fiberglass material, f.o.b., Waterville, Ohio, in 1960, was as follows:

Width	Cents per lineal foot
12-inch	1.5
16-inch	2.0
20-inch	2.5
24-inch	---
36-inch	5.0

Some drainage contractors charge an additional cent per foot for installation.

Stabilizing mats are frequently placed over the top of tile joints to keep soil out of the tile line. Both vinyl and polyethylene mats are available. The vinyl, soft and flexible, is made in gray and black colors. The thickness is about 12 to 15 mils.

The trade name for the polyethylene mat is Eng-O-Lite, a fairly rigid translucent mat of high density and low pressure. It is approximately 10 to 12 mils thick. The mat is supplied in rolls of 8-, 9-, 12-, 16-, and 24-inch widths.

Duramat is a fiberglass mat that is coated with bitumen on both sides. The bitumen imparts some stiffness and increases the thickness to perhaps 30 to 40 mils. For unstable soils, it is installed in the bottom of the tile trench prior to laying the tile. This can be done with a special attachment that unrolls the mat as the trenching machine progresses. Probably, the 9-inch width is the minimum that should be used.

Duramat is used extensively in Indiana and Michigan as a complement to Tile-Gard. Sometimes it is used alone without Tile-Gard. Maryland also reports some use of Duramat. It is supplied in rolls of widths 2, 3, 4, 6, 6-1/2, 9, 12, and 18 inches.

Bituminous fiber pipe is also being used for subsurface drainage in some locations. It is made of creosote- or pitch-impregnated fiber. This pipe usually comes in 8-foot lengths, with the size and spacing of perforations through the walls optional to the purchaser. Sections are joined by split-ring collars. The principal drawback to the 8-foot fiber pipe stems from the fact that most western tile-laying machines are built to handle short lengths of pipe. However, a conventional tile-laying machine has been modified by a contractor in Imperial Valley, Calif., so as to be able to lay 8-foot lengths.

Surface Drains

Surface drains are dug ditches that are often subjected to erosion, sloughing, and infestation with water-loving plants such as tules and reeds. Maintenance of these drains constitutes a major problem in some areas. An economical soil stabilizer to be applied to the banks, but which will not restrict permeability, is needed.

Heavy jute mesh and twisted paper-fabric mesh (Bemis Mulchinet and Bemis Erosionet) have possibilities, but these materials present problems on steep side slopes. Materials used for canal linings are generally not satisfactory, owing to the fact that they have near zero permeability.

At places where surface flow enters the surface drains, permanent well-constructed chutes or drops are necessary. Concrete, wood, plastic aprons, asphalt

planking, butyl rubber aprons, or any material highly resistant to erosion by rapidly flowing water can be used.

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Runoff Control

Numerous tests have been made on various materials to control infiltration and runoff. These materials include soil stabilizers, plastic fiber or other mesh or net covers, asphalt mulches, and plastic and other chemical stabilizers to facilitate reveg-

etation. Sod-based rotations, improved crop residue management, and new tillage methods have been very effective throughout the country in improving infiltration and reducing erosion and sedimentation from periods of revegetation without chemical or mechanical stabilizers.

Infiltration Control Through Use of Soil Stabilizers

Several experiments in Iowa were conducted, to compare plastic films, asphalt mulches, straw mulches, and various vegetative covers as soil stabilizers. From these comparisons the effectiveness of the covers in controlling infiltration while vegetation was being established in exposed subsoil areas was determined. A complete cover of plastic film will obviously cause all precipitation to run off. Partial coverings of plastic films and perforated plastic films have given partial reduction in infiltration. A covering of water-emulsion asphalt has given near complete runoff if the surface is completely covered. Water-emulsion asphalt at the rate applied (0.2 gallon per square yard) soon cracked and checked, resulting in somewhat less runoff than where the surface was completely covered. Crop residue mulches applied at rates of several tons per acre have given almost complete infiltration of precipitation water on the soil materials studied in Iowa.

Evaluation studies of a number of organic cationic chemicals as stabilizing agents for Iowa loess soils have been conducted for the Iowa Highway Commission by the Iowa Engineering Experiment Station.

A quaternary ammonium chloride known commercially as ARQUAD 2HT was considered especially promising from the standpoints of economic feasibility and improvement of immersed compressive strength, moisture absorption, and swelling. It reduced the plasticity index of soils and resulted in flocculation of the clays in silty soil, a substantial increase in soaked bearing strength, a decreased cohesion in airdry soil, and an increased resistance to physical weathering.

The immersed strength and the airdry strength of silty loam treated with large cationic materials are increased by the addition of various polyacids and can be further increased by the addition of small amounts of ferrous carbonate. In the Iowa investigations, highest strengths were obtained by combinations of polyacrylic acid and ferrous carbonate with two large organic cationic materials, ARMAC T and ARQUAD 2HT.

Infiltration improvement through use of soil stabilizers or soil conditioners mixed with the soil has received limited attention in the Eastern United States.

Soil-aggregating chemicals such as vinyl acetate, malic acid, and hydrolyzed polyacrylonitrile have been mixed with soil to make water-stable aggregates. When used on single-grained, poorly structured soils, infiltration, permeability, and aeration of the treated soil are improved. Results from laboratory and field tests show positive benefits for application of this type material on many soils. The effects are not marked on soils that are well aggregated to begin with, but the aggregation produced by conditioners causes extensive physical changes in poorly structured soil. Soil conditioners do not work with some soils, and their effects with other soils are only temporary.

Materials need to be applied at the rate of 1 pound per 100 square feet, which means a rate of application in excess of 400 pounds per acre. With the material costing $1 per pound or more, the cost per acre would be $400. Because of expense of material

and because cost of manufacture could not be reduced, these materials are no longer available.

Runoff Management Through Use of Porous Covers

Considerable research has been conducted and is being continued at several locations on runoff management to reduce rate of water movement to facilitate revegetation. Various methods and materials are under study.

Heavy jute mesh.—The jute matting is used to stabilize soil surfaces during the establishment of grass seedlings (fig. 13). The matting serves as a mulch to keep the soil from drying rapidly and crusting. The matting protects the soil surface from the energy of raindrops and from wind erosion, and serves to reduce the velocity of runoff waters over the soil surface. The matting may be used on slopes, ditches, and waterways where such protection is required.

FIGURE 13.—Jute netting on steep road bank to assist in establishing vegetative cover.

The matting or mesh is woven from jute yarn, approximately 3/16-inch in diameter, spaced on 3/4-inch centers to form the mesh. Jute is an organic material. Physical, not chemical, action is responsible for the desired effects. The effects are obtained solely from the protection offered by the low density, inert material. The jute decays and adds organic material to the surface. It is nontoxic and does not have to be removed.

Jute mesh was used by the Soil Conservation Service in the grade stabilization program on the Farwell Irrigation Project in Nebraska. Approximately 1, 100 square yards were installed on the Farwell Project in the summer of 1960 and additional amounts were installed in 1961. This material has also been used on Public Law 46 installations in Nebraska by the Soil Conservation Service. It has been used on channel stabilization where it was necessary to take runoff flows immediately and where velocities were expected to be relatively high. The Soil Conservation Service reports, "It has been installed approximately in accordance with supplier's recommendations and although some minor erosion under the mat has occurred, it has not been serious. Good stands of grass are now in all of the locations where this jute was used."

The jute mesh will decay sometime after the first season. It would not be effective over a long period of time if a vegetative cover were not established. It must be installed over a prepared, smooth soil surface. No problems of toxicity have been reported.

The cost is about 20 cents per square yard. This is a commonly used, imported material, and reduced cost would result principally from the shipment of large amounts to a single location.

Twisted-paper fabric mesh.—The twisted-paper mesh is used to stabilize soil surfaces during the establishment of grass seedlings (fig. 14). The mesh serves both as a mulch and as a means of holding mulches of straw or hay in place. This protects the soil surface from the energy of raindrops and from erosion by wind and runoff water. It also reduces the rate of soil drying and protects grass seedlings from the wind.

This mesh is woven from a twisted-paper fabric manufactured from natural kraft paper. It retains about 75 percent of its tensile strength when wet. It is available in varying mesh sizes. Like jute, it is an organic material. Physical, not chemical, effects are obtained solely from the physical protection offered by the low density, inert material. The paper decays, adds organic material to the soil, and does not have to be removed. The twisted-paper mesh has been utilized by the Soil Conservation Service on watershed projects in Nebraska. It has been most successfully used as a restraining material for straw or hay mulches. It has a particular value where equipment cannot be used to anchor mulches.

The paper mesh will decay sometime after the first season and would not be effective over a long period if vegetative cover were not established. It must be installed over a prepared, smooth seedbed and preferably over a mulch of straw or hay.

The material costs from 4 to 8 cents per square yard, depending upon the weight and size of mesh. It is a domestically available product. Great reductions in price are probably not possible.

Plastic covers have been used with limited success to protect newly shaped and seeded areas. Polyethylene with 2- or 4-mil thickness has been used to cover new

FIGURE 14.—Berm of floodway seeded to native grass and mulched with hay. The mulch is held in place with paper netting, which is never removed.

seedings on steep areas during establishment. White or yellow plastic gives best results. This allows light for plant growth, yet ground temperatures beneath these colors are not raised to a point where plants are damaged.

Field tests show that plastic covers give good erosion control during the grass establishment period on newly formed roadbanks, water spillways, or similar critical areas. Under some conditions this method of protection for seedlings can be substituted for sodding. Usual costs for sodding are around 4 cents a square yard, or $194 per acre. Covers are only used for a short time and are removed as soon as grass is established.

While these plastics are satisfactory under some conditions, the problem of anchoring plastic covers in place without damaging the grass still needs to be worked out. There does not seem to be any satisfactory answer to this problem.

Cost of plastic material is around 5 cents per square yard, so material to cover an acre will be about $250.

Vegetable Fibers, Asphalt Mulches, Plastic, or Other Chemical Soil Stabilizers

The following materials have been tested as soil stabilizers to facilitate revegetation.

1. Mulches of wheat straw that had gone through a combine and any kind of dried and baled prairie hay were used. The mulches were spread uniformly on the surface, using a mulch spreader. The mulches were anchored with rapid-curing and hard-setting liquid asphalt sprayed directly into the mulch blower, or they were applied and then anchored with a suitable packer.

Five thousand pounds per acre of wheat straw or 4,000 pounds per acre of prairie hay uniformly anchored with a colter disk packer were found completely effective in holding runoff water, preventing erosion, and facilitating germination of grass and alfalfa seeds on sloping land. Of the five types of packers tested, the disk packer proved best. The disk packer was best running across the slope. The best depth of penetration of disks was about 2 to 2-1/2 inches. The mulch that was punched into the soil surface acted as little check dams against running water and facilitated penetration of the water into the soil. Much of the mulch was left standing. This orientation of the mulch was most effective against erosion by wind, and facilitated germination of grass seeds best. Flattened mulch caused some smothering of seedlings, especially if the quantity exceeded 4,000 pounds per acre. The mulch held from 85 to 100 percent against erosion by water. Straw was slightly poorer than hay for this purpose. Coverage of ground surface with grass 7 weeks after seeding was 100 percent under hay mulch and 90 percent under straw mulch.

If a construction slope exceeds 3:1 but does not exceed 20 to 30 feet in length, 400 gallons per acre of rapid curing cutback asphalt (RC-3) or asphalt emulsion mixed with the above-mentioned quantities of straw or hay gave adequate protection against runoff and erosion in the Manhattan, Kans., area with average rainfall of 32 inches per year. The mulches are bulky and therefore are practical only where they are available locally. They appear to be about equally effective on sandy and fine-textured soils.

Costs are $15 per ton for hay or straw, delivered, in the Manhattan, Kans., area; cost of applying the mulch is $30 to $40 per acre. Total cost of mulch packed with disk packer is $89.49 per acre.

If asphalt is used to anchor the mulch the cutback asphalt costs 12 cents per gallon and the asphalt emulsion, 25 cents per gallon, carload lots, f.o.b. Manhattan, Kans. Total estimated cost of mulch plus 400 gallons per acre of asphalt treatment is $200 per acre.

2. Wood cellulose fiber for mulching is manufactured in such a manner that after agitation in a slurry tank with fertilizer, grass seeds, water, and an additive that might be needed to anchor the fibers on the ground surface, the fibers in the slurry become uniformly suspended. When the slurry is sprayed on the ground, it forms a blotterlike ground cover impregnated uniformly with grass seed. The manufacturer claims that the cover allows percolation of rainwater to underlying soil, facilitates seed germination, and reduces runoff and erosion. Additive used was a resinous material of unknown origin and chemical composition.

Preliminary tests with this material on level ground were encouraging for controlling wind erosion, but on sloping ground with 3:1 slope and 20-foot length the results

were not encouraging. The cover, composed of 1,000 pounds of fiber per acre with 18 gallons per acre of resin (Resyn) mixed with the fiber, washed readily down the slope under heavy rains amounting to 2.51, 7.28, and 4.19 inches during April, May, and June, respectively, at Manhattan, Kans.

A suitable method of anchoring the fiber to the ground surface has not been found. Resinous materials, if applied in sufficient quantities, may give sufficient anchorage but will raise the cost of the treatment and may tend to seal the surface and restrict percolation of water through the fibrous cover.

The cost is $120 per ton, delivered. Cost of suitable cementing (anchoring) agent, if it could be found, is unknown.

3. Asphalt emulsion and cutback asphalt sprayed on the surface as thin films stabilize the soil against erosion by wind and water and facilitate germination and growth of grass. The asphalts are natural bituminous materials in liquid form, products of the oil industry, and either positively or negatively charged (cationic or anionic). Slow, medium, and rapid curing (SC, MC, and RC) materials are available for cutbacks. The emulsions are usually fast curing (setting hard rapidly).

The asphalt emulsion, diluted 1:1 with water and sprayed at the minimum rate of one-fourth gallon per square yard of concentrate (1,200 gallons per acre), was just barely sufficient to give reasonably effective control of rill erosion on 3:1 slopes of silty clay soil (table 7). Grass was seeded before the surface was sprayed with asphalt. Ground cover by grass 3 months after treatment was 72 percent on the average as compared with 90 to 100 percent with 4,000 pounds per acre of straw and hay mulch anchored with a disk packer. The asphalt film was virtually nonporous and almost all the water that fell as rain ran off. Therefore, it is important that seeds be placed on or in moist soil before the asphalt is sprayed on the surface.

Results in another test with cutback asphalt sprayed at the minimum rate of one-fourth gallon of concentrate per square yard were about the same as with asphalt emulsion, provided the cutback was heated to facilitate spraying. Dilution of cutback with kerosene to facilitate spraying resulted in some killing of grass seedlings.

The materials facilitated runoff and did not reduce it. Therefore, they are more suited for purposes of concentrating runoff water into channels or reservoirs where the water may be used for whatever purpose is intended. On sandy soils, the asphalt films from the above-mentioned rate of application last from 6 months to 1 year, but on silty clay and clay they disintegrate within 2 or 3 months due to swelling and contraction of the soil.

Asphalt emulsion costs about 25 cents per gallon in 55-gallon drums in carload lots, f.o.b. Manhattan, Kans. Cutback asphalts cost about 12 cents on the same basis. Total cost of the above-mentioned treatments was $247 per acre for cutback asphalt and $335 per acre for asphalt emulsion.

Cutbacks are byproducts of the petroleum industry and their cost in Kansas includes principally the cost of handling. They are readily available in large volumes. Asphalt emulsions are somewhat less readily available, since their source is principally from Venezuela.

4. Resin-in-water emulsion (when sprayed on the surface) has been tested to stabilize the soil against erosion by wind and water without inhibiting penetration of rain-

TABLE 7.—Surface films to stabilize silty clay soil on 3:1 slope against erosion by water. Treated March 27 to April 7, 1961. Treatments are listed in order of highest to lowest effectiveness

Material and dilution1/	Rate of Application	Amount of rill erosion		Ground covered by grass June 20	Estimated cost per acre
		May 12	June 20		
	Gal./sq. yd.	Tons/acre	Tons/acre	Percent	
Asphalt emulsion, 1:1	3/8	0.0	1.6	60	$487.50
Do	1/4	.2	4.4	72	335.00
Cutback asphalt, 1:12/	3/8	.03	12.3	45	338.00
Resin emulsion, 1:1	3/8	.9	18.3	75	584.00
Cutback asphalt, 1:12/	1/4	.4	24.1	45	246.67
Resin emulsion, 1:1	1/4	1.8	23.0	80	398.50
Resin emulsion, 1:4	3/8	3.5	29.8	55	586.50
Latex emulsion, 1:8	3/64	.6	34.0	50	390.00
Asphalt emulsion, 1:1	1/8	4.4	31.6	58	182.50
Resin emulsion, 1:4	1/4	4.5	33.6	65	401.00
Do	1/8	6.0	32.7	70	215.50
Latex emulsion, 1:8	1/32	4.2	35.6	65	270.00
Cutback asphalt, 1:12/	1/8	6.0	43.6	48	154.00
Resin emulsion, 1:1	1/8	7.1	44.2	85	213.00
Latex emulsion, 1:8	1/64	4.8	51.7	70	150.00
Check (no treatment)	----	14.7	47.1	42	0

1/ Ratios 1:1, 1:4, and 1:8 indicate ratios of material to water.

2/ Diluted with kerosene.

water into the soil and to facilitate germination and growth of grass. It is also proposed that dilution with water and spraying in sufficient quantity for the material to penetrate the soil surface 1 to 2 inches in depth will keep down dust that otherwise would arise from foot or vehicle traffic.

It is a liquid emulsion of water and natural petroleum resins. The resins have high resistance to weathering and soil bacteria. When diluted 1:1 with water and sprayed on the surface at a rate of one-eighth gallon of concentrate per square yard (600 gallons of concentrate per acre), the material was completely effective in stabilizing a highly erodible sandy loam soil against 85-mile-per-hour winds for at least 3 months after treatment. The material penetrated the soil surface and left the surface highly permeable to water. Water from heavy rains (7 inches) penetrated the treated surface readily and left it virtually intact. The untreated surface, on the other hand, slaked smooth, and much of the water apparently ran off.

On silty clay with a 3:1 slope 20 feet long, the results were entirely different. The clay apparently absorbed the material and a few weeks after treatment caused the formation of loose granules, which were readily eroded down the slope by runoff water.

Germination and growth of grass and alfalfa were generally better than on the untreated, bare areas. The material apparently binds sands, loamy sands, and sandy loams and makes them resistant to erosion by wind and water and, at the same time, facilitates penetration of rainwater; but on fine-textured soils it has failed to produce these effects and has caused the soil surface to loosen and be readily eroded by runoff water.

The cost of resins is 30-1/2 cents per gallon in 55-gallon drums, carload lots, f.o.b. Manhattan, Kans. Total cost of treatment was about $200 and $400 with a 1/8- and 1/4-gallon per square yard rate, respectively.

5. Latex emulsion has been proposed to stabilize the soil surface against erosion by wind and water and to facilitate germination and growth of grass when sprayed as a thin film on a seeded ground surface. It has an elastomatic polymer (synthetic rubber latex) base. Its chemical composition is not known to us. When sprayed lightly it forms a thin, weblike film through which grass seeds emerge readily. The porous film is supposed to be receptive to percolation of water into the soil.

The emulsion diluted 1:8 with water and sprayed on silty clay with a 3:1 slope at rates up to 3/64-gallon per square yard of concentrate failed to control rill erosion adequately (table 7). Also, apparently a considerable proportion of the seeds were washed away. The emulsion broke as soon as it hit the surface and produced a pliable, porous latex film on the surface. However, the amounts of emulsion were too small to produce a film that would cover the surface adequately. On the other hand, adequate cover to control erosion might have reduced percolation of water into the soil and increased runoff.

The cost of the emulsion is $1.60 per gallon in 50-gallon drums. Cost of the treatment with amount of latex sufficient to control rill erosion is estimated to be about $1,000 per acre.

6. Water-dispersible starch compounds when sprayed on a seeded soil surface were proposed to control wind erosion until such time as seedlings covered the surface of the ground. This is a hydrolyzed starch compound from cereal crops. The material remains water-dispersible after application and readily disappears with rain.

Starch compounds were found unsatisfactory to control wind or water erosion, because the film disappeared with the first moderate rain. Rates up to 1/40 pound is 1/4-gallon of water per square yard were used.

The cost is from 3 to 10 cents per pound. Total cost of application is $60 to $150 per acre.

None of the materials (2) through (6) excels the well-anchored vegetative mulch from the standpoint of cost and effectiveness in decreasing runoff and controlling wind and water erosion of denuded land until such time as permanent vegetation can be established. All the materials tested, except starch, if applied in sufficient quantity and concentration and if sufficiently anchored would control erosion by wind or water on flat or sloping land, but at a cost substantially higher than that for the well-anchored vegetative mulch.

It is apparent from these investigations that an ideal type of organic film to decrease runoff and control wind and water erosion should be insoluble or indispersible in

water, durable, and yet porous enough to allow percolation of water and adequate seedling penetration. Apart from the vegetative mulches, the resin emulsion appears to be the only one that meets all these requirements, but only on sandy soils.

Channel Stabilization

1. Jute thatching has been used with success to protect formed channels or waterways where flash runoff cannot be diverted. Specifications for the material are as follows:

> Cloth shall be of uniform open plain weave of undyed unbleached single jute yarn average 190 pounds per spindle of 14, 400 yards. The yarn shall be of a loosely twisted construction having an average twist of not less than 1. 6 turns per inch and shall not vary in thickness by more than one-half its normal diameter.
>
> The cloth shall be woven as follows:
> Width--45" plus or minus 1"
> 78 warp ends per width of cloth
> 41 weft ends per yard
>
> In any one shipment of approximately 50 linear yards, weight of cloth to average 1. 8 pounds per linear yard with a tolerance of plus or minus 5 percent.

Tests at the Stillwater Outdoor Hydraulic Laboratory, Stillwater, Okla., and extensive field trials in the Northeast have shown that this material can do an outstanding job of stabilizing soil (fig. 15).

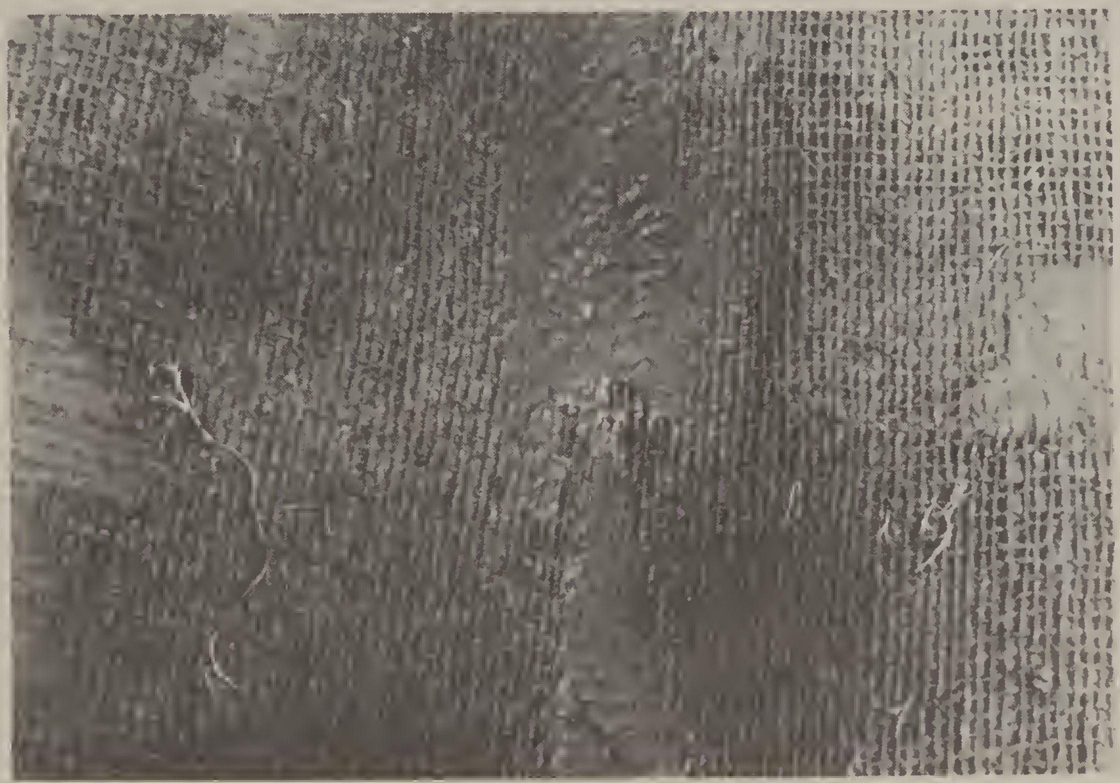

FIGURE 15.–Fine mesh jute thatching in experimental waterway after a test flow. The jute strands are approximately one-fourth inch in diameter.

Newly shaped and seeded waterways and ditches can be protected immediately by jute thatching applied over smoothed areas and anchored in place with pins. Properly laid jute forms a close bond with the soil and has a permissible velocity of about 3.6 feet per second. The material can be left in place and seems to aid the growth of grass, owing to its mulching effect. The use of this material eliminates the need for sodding, which costs about $194 per acre.

Jute thatching must be properly applied to give good results. Its effectiveness is limited where water flow exceeds 3.6 feet per second. The cost of material is less than 20 cents per square yard, so material for one acre would cost around $968.

2. Cellular concrete blocks are placed in shaped bank slopes to protect streambanks from erosion during flood flows. The cellular units are of a size convenient to handle (weight 75 lb.) and are joined together by keyed tongue-and-groove joints so as to form a protective cover for an eroding stream. The cells are placed perpendicular to the slope of the bank and to the stream's edge.

The cellular blocks made hand placement easier by keeping the weight down; make possible shrub plantings in the openings, which help to hold blocks in place against high stream velocities; and produce a block with greater roughness than that of a smooth block. The depth of the block must be sufficiently great so the block will be able to resist the boundary shear stress. In a field test during an extreme flood, the cellular blocks were practically unharmed while nearby stone revetments up-and-downstream of the cellular block installation were severely damaged. A high-quality concrete is required, so that the blocks can withstand the forces of disintegration.

In order for cellular concrete blocks to be effective as a streambank revetment measure, they must be placed flush with the bank and firmly anchored at the toe of the slope. The depth of the block must be based on the boundary shear stress expected from the stream velocities. Cellular concrete blocks can be produced in commercial block machines. Costs of the blocks usually run slightly higher than that for quarried stone.

3. Other materials used to stabilize waterways have been discussed under "Runoff Management Through Use of Porous Covers." For major stabilization, linings, as discussed under "Reduction of Losses From Storage and Conveyance," are often used.

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PROJECTION OF RESEARCH AND DEVELOPMENT NEEDS

This report has been limited to a brief summary of the results of the current research and development studies in utilization of new materials and methods for water resource management. Only the most significant and promising areas have been reported. Secondary studies and studies made by other agencies, groups, and companies have necessarily been unreported, due to space limitations.

The potential of new materials and methods in meeting and correcting many of the Nation's soil and water resource management problems is fully apparent. The major role that has been played by industry, by Federal and State agencies, and by individual researchers has vividly demonstrated the potentials of these new materials. But, in view of these vast potentials, the current level of research and development that is specifically directed toward the development and utilization of these new materials is extremely meager.

For full exploitation of new materials and methods in meeting resource problems, it is imperative that the close and effective cooperative relations that exist between industry and Federal research agencies be continued and even strengthened. Part-time and "byproduct" types of research approaches must be replaced by fully staffed and implemented research programs that can take full and timely advantage of each new development.

An industry becomes more and more aware of the technical requirements of materials for evaporation suppression, seepage control, and for control of other elements that affect the Nation's water resource balance, it should develop new screening techniques, new product evaluation procedures, and consider new formulation and fabrication techniques. Similarly, as water resource research scientists become more aware of, and familiar with, the basic characteristics of families of chemicals, groups of plastics, and other types of new materials, they must expedite laboratory and field research and development studies to assure rapid application of these materials in meeting resource problems.

As the President's intensified Resource Protection program develops, the program objectives will form an important basis for the expanded utilization of new materials. Only through such intensified programs can the full utilization of the products of the Nation's scientific discoveries be applied to the solution of its resource problems.

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